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FULL-SCALE PROPELLER DISK WAKE SURVEY AND BOUNDARY LAYER VELOCITY PROFILE MEASUREMENTS ON THE 154-FOOT SHIP R/V ATHENA

BY

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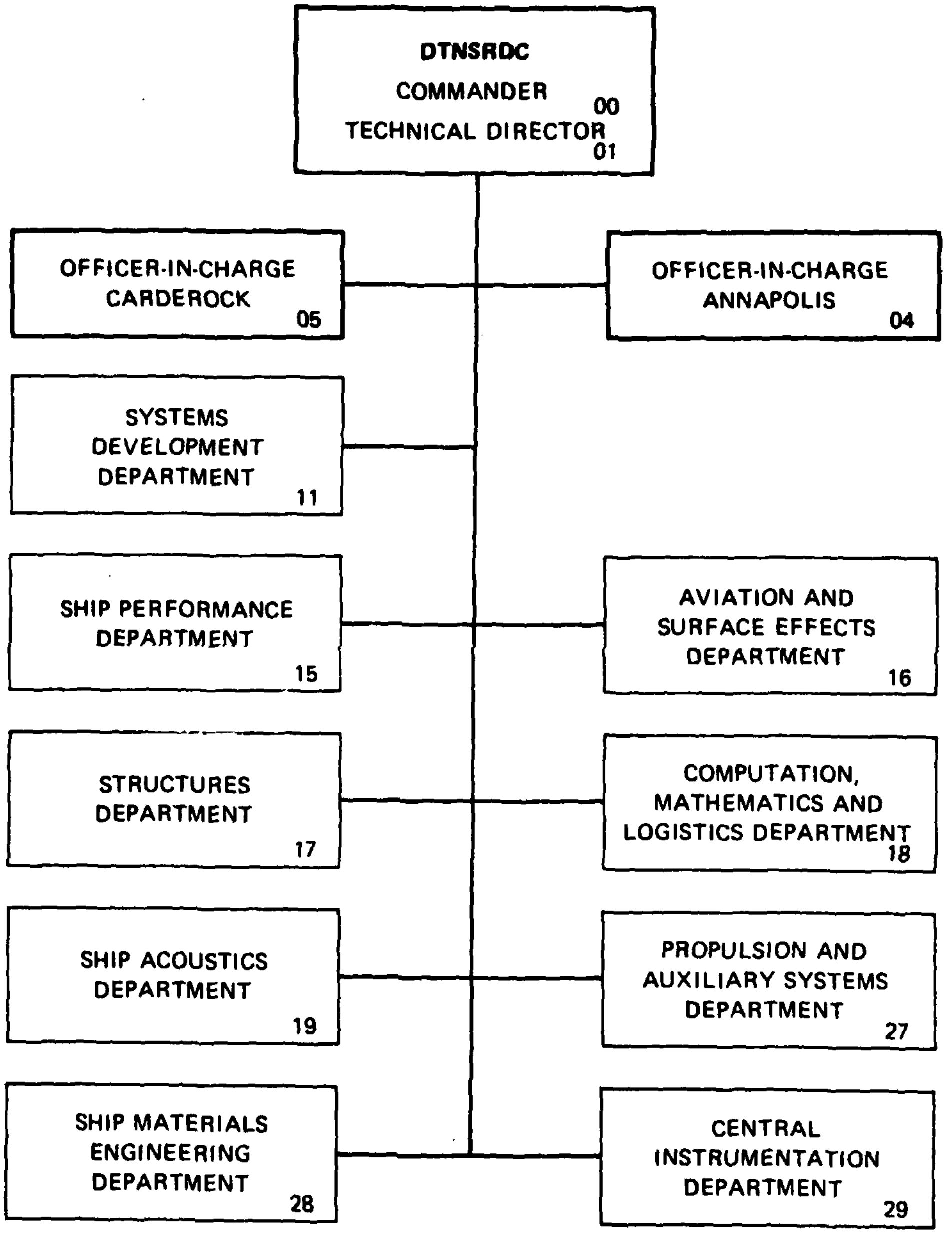

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Measurements of propeller disk velocity components have been made for the 154-foot ship R/V ATHENA. Longitudinal, tangential, and radial velocity components are presented for three planes perpendicular to the propeller shaft for full-scale speeds of 9 and 15 knots. In addition, several boundary layer velocity profiles were measured on the full-scale hull. Non-dimensional velocity profiles are presented for several speeds. Finally, the results of an attempt at measuring time dependent velocities ahead of an operating propeller are presented.

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NOTATION

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
A_N	COS COEF	The cosine coefficient of the $N^{\underline{th}}$ harmonic*
B_N	SIN COEF	The sine coefficient of the $N^{\underline{th}}$ harmonic*
C	C	Pressure reading at center hole of 5-hole pitot tube
D	---	Propeller diameter
J_V	J_V	Apparent advance coefficient $J_V = \frac{V}{nD}$ (dimensionless)
N	N	Harmonic number
n	---	Propeller revolutions
P	P	Pressure
r/R or x	Radius or RAD.	Distance (r) from the propeller axis expressed as a ratio of the propeller radius (R)
R_n	R_n	Reynolds number
R1, R2	R1, R2	Pressure reading at radial holes of 5-hole pitot tube
T1, T2	T1, T2	Pressure reading at tangential holes of 5-hole pitot tube
U/U_∞	U/U_∞	Non-dimensional longitudinal velocity measured by means of boundary layer pitot tubes
V	V	Actual model or ship velocity
$V_b(x,\theta)$	---	Resultant inflow velocity to blade for a given point
$\overline{V}_b(x)$	---	Mean resultant inflow velocity to blade for a given radius
$V_r(x,\theta)$	VR	Radial component of the fluid velocity for a given point (positive toward the shaft centerline)

(*see footnote on page xii)

NOTATION (CONTINUED)

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$\overline{V}_r(x)$	---	Mean radial velocity component for a given radius
$V_r(x,\theta)/V$	VR/V	Radial velocity component ratio for a given point
$\overline{V}_r(x)/V$	VRBAR	Mean radial velocity component ratio for a given radius
$V_t(x,\theta)$	VT	Tangential component of the fluid velocity for a given point (positive in a counterclockwise direction looking forward)
$\overline{V}_t(x)$	---	Mean tangential velocity component for a given radius
$V_t(x,\theta)/V$	VT/V	Tangential velocity component ratio for a given point
$\overline{V}_t(x)/V$	VTBAR	Mean tangential velocity component ratio for a given radius
$(\tilde{V}_t(x)/V)_N$	AMPLITUDE	Amplitude (B_N for single screw symmetric; C_N otherwise) of Nth harmonic of the tangential velocity component ratio for a given radius*
$V_x(x,\theta)$	VX	Longitudinal (normal to the plane of survey) component of the fluid velocity for a given point (positive in the astern direction)
$\overline{V}_x(x)$	---	Mean longitudinal velocity component for a given radius
$V_x(x,\theta)/V$	VX/V	Longitudinal velocity component ratio for a given point
$V_x(x)/V$	VXBAR	Mean longitudinal velocity component ratio for a given radius
$(\tilde{V}_x(x)/V)_N$	AMPLITUDE	Amplitude (A_N for single screw symmetric; C_N otherwise) of Nth harmonic of the longitudinal velocity component ratio for a given radius*

NOTATION (CONTINUED)

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
x/L_{WL}	x/L_{WL}	Non-dimensional longitudinal location of boundary layer pitot tubes
ϕ_N	PHASE ANGLE	Phase angle of Nth harmonic*

*The harmonic amplitudes of any circumferential velocity distribution $f(\theta)$ are the coefficients of the Fourier Series:

$$f(\theta) = A_o + \sum_{N=1}^{N} A_N \cos(N\theta) + \sum_{N=1}^{N} B_N \sin(N\theta)$$
$$= A_o + \sum_{N=1}^{N} C_N \sin(N\theta + \phi_N)$$

NOTATION (CONTINUED)

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$1-w(x)$	1-WX	Volumetric mean velocity ratio from the hub to a given radius

$$1-w(r/R) = \left[\frac{2 \cdot \int_{r_{hub}/R}^{r/R} (\bar{V}_{x_c}(x)/V) \cdot x \cdot dx}{(r/R)^2 - (r_{hub}/R)^2} \right]$$

where $\bar{V}_{x_c}(x)/V = \int_0^{2\pi} \left[\frac{V_{x_c}(x,\theta)}{2\pi V} \right] d\theta$

and $V_{x_c}(x,\theta)/V = (V_x(x,\theta)/V) - (V_t(x,\theta)/V) \tan(\beta(x,\theta))$

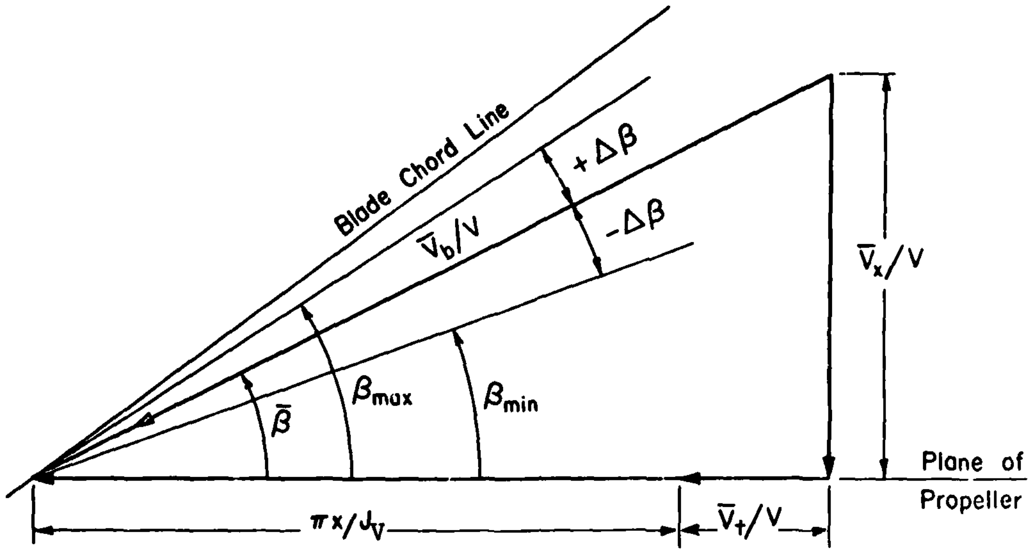
CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$1-w_v(x)$	1-WVX	Volumetric mean velocity ratio from the hub to a given radius (without the tangential velocity correction)

$$1-w(r/R) = \left[\frac{2 \cdot \int_{r_{hub}/R}^{r/R} (\bar{V}_x(x)/V) \cdot x \cdot dx}{(r/R)^2 - (r_{hub}/R)^2} \right]$$

CONVENTIONAL SYMBOL	SYMBOL APPEARING ON PLOTS	DEFINITION
$\beta(x,\theta)$	---	Advance angle in degrees for a given point
$\bar{\beta}(x)$	BBAR	Mean advance angle in degrees for a given radius
$+\Delta\beta$	BPOS	Variation of the maximum advance angle from the mean for a given radius

NOTATION (CONTINUED)

$-\Delta\beta$	BNEG	Variation of the minimum advance angle from the mean for a given radius
θ	Angle in degrees	Position angle (angular coordinate) in degrees



VELOCITY DIAGRAM OF BETA ANGLES

ENGLISH/SI EQUIVALENTS

ENGLISH	SI
1 inch	25.400 millimetres [0.0254 m (metres]
1 foot	0.3048 m (metres)
1 foot per second	0.3048 m/sec (metres per second)
1 knot	0.5144 m/sec (metres per second)
1 degree (angle)	0.01745 rad (radians)
1 inch Water (60°F)	248.8 pa (pascals)

ABSTRACT

Measurements of propeller disk velocity components have been made for the 154-foot ship R/V ATHENA. Longitudinal, tangential, and radial velocity components are presented for three planes perpendicular to the propeller shaft for full-scale speeds of 9 and 15 knots. In addition, several boundary layer velocity profiles were measured on the full-scale hull. Non-dimensional velocity profiles are presented for several speeds. Finally, the results of an attempt at measuring time-dependent velocities ahead of an operating propeller are presented.

ADMINISTRATIVE INFORMATION

This work was performed under the Controllable-Pitch Propeller Research Program sponsored by the Naval Sea Systems Command (NAVSEA 05R) and administered by the David W. Taylor Naval Ship R&D Center (DTNSRDC). The project was funded under Task area S0379001 and DTNSRDC Work Unit Numbers 1524-607, 1524-612, and 1524-641.

INTRODUCTION

In order to properly design a propeller for any naval craft, it is necessary to obtain an accurate estimate of expected operating loads. The maximum time-average and alternating loads for prescribed operating conditions at full-scale cannot presently be predicted from the results of model-scale experiments. Analytical predictions must be made using information about the flow into the propeller (i.e., the wake). This is especially true for naval surface combatants which operate at high speeds.

Because of the need for full-scale experimental data on propeller loadings, a task was developed within the Controllable-Pitch Propeller Research Program under which full-scale wake data, and the relevant model-scale data, could be obtained for surface combatants. The U.S. Navy is

committed to employing controllable-pitch propellers on several new classes of designs including the SPRUANCE-class destroyers (DD 963 class) and the PERRY class frigates (FFG 7 class). High-speed surface combatants such as these require high shaft power and thus have highly loaded propellers. In the design of propellers for high load applications, care must be taken to design the blades and pitch-changing mechanisms so that they possess adequate strength. Should they fail to meet the strength requirement, propeller blades, bolts, and crank disks are subject to fracture.[1]

Designing the propeller to meet the necessary strength characteristics requires an accurate estimate of the maximum time-average and alternating loads under the various operating conditions. High time-average and alternating loads occur during steady full-power ahead conditions and during high-speed maneuvers such as: full-power crashback, full-power crash forward, and full-power turns. In addition, the influence of a seaway may substantially increase the time-average and alternating loads.

In order for any of these design calculations or load calculations to be made, knowledge of the wake into the propeller disk is needed. Customarily, this propeller disk wake is obtained from an experiment using a model in the towing tank. Little or no information is available to show how well the model wake data represent the full-scale wake. Hence, it was deemed appropriate to pursue the task of measuring the full-scale wake on a surface combatant-type ship which was equipped with controllable-reversible pitch propellers. The results of such full-scale propeller disk wake measurements are documented in this report. The full-scale measurements of propeller disk wake were

[1]References are listed on Page 29.

followed by model experiments to measure wakes in the towing tank and in a wind tunnel.

A brief summary of the entire program of work to measure model and full-scale wakes of R/V ATHENA was presented by Reed and Day[2] in the Twelfth Symposium on Naval Hydrodynamics. Details of the model experiments and correlation with full-scale wake measurements are presented by Hurwitz and Jenkins[3], and Hurwitz and Crook[4], for the wind tunnel and towing tank model experiments, respectively. This report presents the detailed description of the full-scale measurements on R/V ATHENA including instrumentation, trial procedures and measured data.

PROJECT DEVELOPMENT

In order to prepare for the implementation of the project, two vital and equally important elements had to be considered. First, it was necessary to identify and obtain a vessel constructed and equipped to appropriate specifications. Second, it was necessary to develop, test, calibrate, and install instrumentation designed especially for the project.

SELECTION OF THE R/V ATHENA

Once it had been decided that full-scale wake field and boundary layer data were required to define scaling deficiencies, and validate scaling procedures as they were developed, a search was begun to identify a ship which could be employed for experimental purposes. The ship selected was the Research Vessel (R/V) ATHENA, a converted gunboat of the PG 84 class, operated by the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), and used primarily as a vehicle for investigation of towed array performance. The R/V ATHENA is a twin-screw, transom-stern ship, equipped with controllable-pitch propellers, twin rudders, and roll fins.

Power is provided either by twin Cummins 750-V12 diesel engines, which can furnish a maximum speed of 16 knots; or by a General Electric LM-1500 gas turbine, which increases this speed capability to 40 knots.

Figure 1 details the body plan, and bow and stern profiles of the R/V ATHENA. Further descriptive information about the ship is available in photographs presented in Figures 2 through 8.

PRETRIAL EXPERIMENTS

Prior operating experience with the R/V ATHENA has established that she could be propelled in a straight line on one shaft. Thus, a decision had to be made as to whether she should be towed by one or two other ships, or propelled on one shaft while measurements were taken from the other. The latter method had the advantage of being simpler and less costly; however, if the R/V ATHENA could not be propelled with minimum yaw angles, a tradeoff would have to be made between propelling on a single shaft and making measurements in the wake of another ship. In order to investigate these options, a series of model experiments was performed.

Experiments were carried out using the existing model of the R/V ATHENA (DTNSRDC Model 4950-1), which is built of mahogany to a scale ratio of 8.25. The first experiments were flow visualization studies, which were performed in the Circulating Water Channel (CWC) at DTNSRDC, and were designed to determine flow conditions at various yaw angles. The second set of experiments dealt with course-keeping and directional stability. These were performed on Carriage 1 of DTNSRDC, and were intended to determine the rudder angles which would result in stable course-keeping while the model was either towed or propelled on one shaft.

For the flow visualization experiments, the R/V ATHENA was fitted with yarn tufts on her surface, and on pins one inch from the surface. These

were observed in the CWC to determine if unusual flow conditions occurred when the model was yawed from six degrees starboard to six degrees port in two-degree increments. Although flow separation was observed from the mid-span region of the inboard strut, it was determined that that particular flow was independent of the yaw angle, and was present regardless of whether the propeller was powered, windmilling or locked. Examples of these flow visualization experiments are provided in Figures 9 and 10.

Additional information on flow visualization was obtained by ejecting dye from the root and tip of the roll fins in order to establish at which yaw angle the wake of the roll fin impinged upon the action of the propeller. At yaw angles greater than four degrees, the dye pattern from the roll fin entered the propeller disk. Therefore, four degrees was established as the allowable limit for yaw angle. The dye streak from these experiments can be observed on the port side of the model in Figure 10.

Course-keeping and stability experiments involved both propelling the model with only the port shaft, and towing the model in the Carriage 1 basin at DTNSRDC. During these experiments, the model pitot tube rake was installed on the starboard shaft of the model. Only the port rudder was varied to change the course-keeping of the model; the starboard rudder was set at zero degrees. The towed model maintained a straight course with no yaw by using 5 degrees of rudder (trailing edge to starboard). The self-propelled model maintained a straight course with no yaw by using only one degree of rudder. Figures 11 and 12 show the self-propelled model with one degree of port rudder and zero degrees starboard rudder.

Having established that the model could propel itself on one shaft with minimal rudder and yaw angles, it was decided that the same method would be adopted for the full-scale trials.

In addition, findings from earlier trial data and self-propulsion experiments indicated that the R/V ATHENA was capable of attaining speeds in excess of 14 knots while operating on a single shaft.

INSTRUMENTATION DEVELOPMENT

Concurrent with pretrial experiments, investigations were conducted to develop appropriate instrumentation, a task considered equally as important as the identification of the appropriate ship. A contract was let with the Department of Naval Architecture and Marine Engineering, University of Michigan, to investigate the feasibility of various types of instrumentation for measuring both the velocity components in the propeller plane and the boundary layer velocity profile for the R/V ATHENA. The contract further stipulated that this feasibility study would be followed by actual development of a set of prototype instrumentation for use in the trial.

University research indicated that water, despite its ready availability, was not the ideal transport medium for measuring wake velocities behind an actual ship. Salt water can corrode instrumentation, distilled water tends to collect air bubbles in lines which distort findings, and deaerated water can never be completely void of air. It was decided, therefore, to design a pneumatic system based on Takahashi's "air-blow system" (Takahashi, et al[5]), and this air-based system became the heart of both wake survey and boundary layer measurement systems. A complete description of the pneumatic pressure measuring system is given in Troesch, et al[6]. An explanation follows here and a schematic representation appears in Figure 13.

An important feature of the system is that it contains Scanivalves, which automatically sequence the air pressure signals from the pitot tube and the air bleed from the ship. Once the vessel has attained a steady speed, the pneumatic system is manually activated and then operates auto-

matically. Figure 14 shows pressure signals generated through processing the ports of a five-hole pitot tube. Initially, pressurized air is ejected from a reservoir, blowing all the water out of the system. This registers as the high plateau on the pressure gauge. The air bleed is then automatically stopped and pressure in the system decreases until equilibrium is reached with the total pressure of the flow. This is registered on the pressure gauge as a rapid decline followed by transition to a lower plateau. At this point, the system signals a computer that equilibrium has been reached and data collection can begin. The computer collects data until the system signals that it must cycle through the bleed sequence again and measure pressure beginning at the next Scanivalve port. It continues this process until all ports have been measured.

As has been stated, the pneumatic system developed by the University of Michigan became the heart of both the wake survey and boundary layer measuring system. Wake survey instrumentation consisted of five-hole spherical pitot tubes, designed in standard fashion with four outside holes located 30 degrees from the center hole as shown in Figure 15, and a 13-hole pitot tube system specifically designed for the project. Figures 15 and 16 present schematics of the 5- and 13-hole pitot tube and Figure 17 shows two views of a lucite construction model of the 13-hole pitot tube. The 13-hole system differed from the classical design of Janes[7] in that it consisted of seven partially redundant five-hole pitot tubes rather than three completely redundant five-hole pitot tubes. (See Figure 16). Four of the holes on the pitot tube are placed on a diagonal between the major axis of a nine-hole pitot tube to serve as either tangential or radial holes for the four other five-hole pitot tubes.

In combination with the central hole of all tubes, these holes form an additional five-hole pitot tube whose axis is rotated 45 degrees relative to the major axes of the other nine holes. Because the holes of this central pitot tube are spaced 20 degrees apart, any velocity within 20 degrees of the central hole will be covered by at least four pitot tube combinations and will have at least two different center holes capable of covering any flow within angles of 20 to 40 degrees. Furthermore, the flow will inevitably be within 20 degrees of at least one of these center holes.

Boundary layer instrumentation consisted of 13 tubes mounted in a rake, which was attached perpendicular to the hull of the ship as shown in Figure 18. Ten of these tubes were total pressure pitot tubes designed to measure total pressure, the value of which includes both dynamic and static pressures. The other three were classical Prandtl tubes which measure both the static pressure and total pressure. Using static pressure data correlated with information on the spacing of tubes from the hull, it was possible to convert all total pressure measurements to dynamic pressure values and thereby into velocity values.

Another novel piece of instrumentation developed for the full-scale trial was an experimental five-hole piezoelectric pitot tube, whose function was to measure the time-dependent flow induced by the propeller. This spherical pitot tube has five piezoelectric differential pressure transducers mounted on its face. A known amount of air pressure is applied to the interior surfaces of these transducers. Changes between interior and exterior pressure cause voltages across the transducers to vary, resulting in a signal which may be digitized and recorded on magnetic tape.

The final instrument developed for the trial was a yaw meter. Since the blades of one propeller were removed and instruments mounted on the shaft, it was evident that the hull would become asymmetrical and that the ship might track with some yaw angle. Model experiments predicted that the angle would be small, but it was believed that it should be measured accurately and recorded for use in correlation experiments with the model in the towing tank.

The yaw meter was designed by Mar, Inc. under a contractual agreement. The company's design, as shown in Figure 20, consisted of a structure resembling a weather vane which was attached by its shaft to the bottom of the ship. A linear variable differential transformer (LVDT) was installed inside the shaft and its end rode up and down on a cam fixed to the bottom of the vane. The cam was designed so that its rise would be linear with the angle of rotation of the vane. The instrumentation was further equipped with a gauge, which could be slipped into a slot in a pod installed on the hull bottom and into a hole in the top of the vane. Divers could thus set the yaw meter at zero and plus or minus 15 degrees, while the ship was in the water, to obtain a calibration.

CHECKOUT AND CALIBRATION

All instrumentation, except the piezoelectric pitot tube, was tested and calibrated in the model basins of either DTNSRDC or the University of Michigan. The boundary layer probes were calibrated at the University of Michigan, and the pitot tubes were calibrated at DTNSRDC. Due to time constraints, however, the piezoelectric pitot tube was only tested at the University and was not calibrated prior to the trial.

The boundary layer probes were calibrated under two different sets of conditions, as described by Troesch[6], et al. The free-stream calibration evaluated the linearity of the probes, the effects of the numbers and sizes of circumferential holes in static pressure tubes, and the effects of flow direction. There were some minor difficulties detected with static pressure measurements, but generally all pressure ports performed in a similar manner, regardless of how they were arranged. For speeds above 10 feet per second (3.05 m/s), the calibration curves of the probes were linear for flow angles up to 30 degrees.

Wake screen calibration experiments were performed to determine how the boundary layer probes would behave in a velocity gradient approximating that of a ship's boundary layer, and whether or not interference between individual pitot tubes was present. To create such a velocity gradient, a wake screen was constructed. This consisted of an 18-inch square (460 mm x 460 mm) wooden frame with layers of screening mounted upon it. The density of the screens ranged from chicken wire to household window screening. Results of experiments behind the wake screen indicated that interference between tubes was minimal, and that probes could indeed detect variations in velocity over an area comparable to the expected full-scale boundary layer thickness.

The pitot tubes were calibrated over a range of angles at several speeds,[8] including 12 knots (6.17 m/s) which was the speed anticipated for the trials. Each five-hole pitot tube was calibrated in the radial and tangential planes at angles from -30 degrees to +30 degrees in five-degree increments. Figure 21 shows a pitot tube in a towing tank calibration run during the air-bleed cycle, and Figure 22 shows the

same tube during the measuring cycle. Pressure components were measured and the pressure differences from which flow directions and magnitude are determined were calculated for both the radial and tangential components. Figures 23 and 24 show calibration data for all pitot tubes plotted on a single graph. The solid lines in the figures indicated calibration curves for a typical pitot tube.

The 13-hole pitot tubes were calibrated in a similar manner. However, due to the many combinations of five-hole pitot tubes used to construct the 13-hole model, the number of angles used for calibration increased significantly. The radial and tangential calibrations had to be repeated for several yaw and pitch angles in order to obtain curves for each of the off-center angles of the five-hole tubes.

The yaw meter was calibrated using a protractor while the ship was in drydock, and was found to be linear up to angles in excess of 45 degrees.

INSTALLATION OF INSTRUMENTATION

To prepare for the trial, the R/V ATHENA was drydocked on the marine railway facilities of the Atlantic Dry Dock Company in Fort George Island, Florida. After the ship's bottom had been cleaned with a high pressure water jet, the condition of the hull surface was fair to good, meaning that the averaged observed roughness of the paint was 2000 to 5000 micro inches rms (50 to 130 microns).

The digital computer, which would record and analyze data, was installed in the instrumentation shack on the after deck of the R/V ATHENA. Also located in the shack were a teletype machine, a printer, a strip chart recorder, an FM tape recorder, a pitch-roll gyroscope, and signal conditioning and amplification instrumentation. The Scanivalve pressure transducer system and the air compressor were located on the deck immediately behind the instrumentation shack as shown in Figure 25.

Other equipment required for the experiments included the shaft torque meter, the rudder angle indicator, the heading indicator, the Kenyon knot meter, the towed knot meter, and the shaft rpm indicator. Leads from all equipment were connected to a patch board in the instrumentation shack. Leads were extended from the patch board to the multiplexer on the analog-to-digital converter and to a strip chart recorder. During each run, all data were digitized, read by the computer, and stored on magnetic tape. The data from the pressure transducer system were also displayed on a strip chart recorder during each run.

In the engine room, the starboard shaft clutch was deactivated so that the ship could be propelled under gas-turbine power with only one shaft turning. This was accomplished by removing one gear, thus blocking all

power from the main reduction gear from reaching the clutch, and installing a clamp on the starboard shaft to prevent it from turning inadvertently. A lever arm was then attached to one flange of the shaft, so that the shaft could be rotated when the angles of the rakes had to be changed. To prevent propeller blade pitch changes, which would have altered the angles of the rakes in the propeller disk, the hydraulic pump for the starboard shaft was disconnected. Finally, to prevent the starboard rudder from moving, the hydraulic rams connected to the starboard tiller arm were isolated from the hydraulic system by a series of valves, and the link connecting the tiller arms of the two rudders was removed from portside and set on a pin installed on the transom. This had the effect of locking the starboard rudder in the zero position, while leaving the port rudder free to operate normally.

Two pairs of pitot tube rakes were installed on the starboard shaft as shown in Figure 26. These consisted of Rakes A and B, which were mounted in the propeller disk, and had four pitot tubes each; and Rakes C and E, with three and six pitot tubes respectively, which were mounted ahead of the shaft struts.

The individual pneumatic pressure lines from the scanivalve system were encased in a flexible tube, and led to the deck from the pitot tubes through D-rings attached to the shaft struts and bottom of the hull, as shown in Figure 26. When the measurement runs were begun, the tubing failed to withstand the forces due to the flow about the hull and shafting. Several of the tubes were cut, and several other tubes twisted or bent; all of which made measurement of the pressures at the pitot tube impossible. The ship was placed in drydock again and it was decided to

place all pneumatic tubing in rigid conduit. Figures 27 and 28 illustrate the rigid conduit for the tubing from the starboard pitot tube rakes and boundary layer probes.

The four starboard propeller blades were removed and replaced with blanking plates, using the crank discs normally associated with propeller blade pitch change action. Rakes A and B were then attached to two opposite blanking plates. Figure 29 shows rake B, with four pitot tubes mounted, attached to the blanking plate. In order to align the rakes with the shaft, the pitch on the crank discs was adjusted. The blanking plates were firmly secured, and, as has been mentioned previously, the hydraulic pump for the pitch mechanism was disconnected. Pneumatic pressure lines from the rakes were led into steel conduit attached to the propeller fairwater, and from there into a funnel shown in Figure 30. The funnel allowed the tubing to twist as the shaft was rotated, and led the tubing into a single large conduit which carried the pressure lines up the transom to the deck.

In order to mount rakes C and E ahead of the struts, the rope guard was removed from the strut bossing and a collar was clamped on the shaft. The two rakes were mounted on the collar, and the rope guard was placed on the shaft ahead of the collar. These rakes were placed 90 degrees out of phase with rakes A and B to minimize interference between the two sets. Pressure lines from rakes C and E were also run aft along the propeller fairwater, and thence to the deck as shown in Figures 7 and 28.

Instrumentation for the port side propeller shaft consisted of two rakes, one with three pitot tubes (designated rake D) and one with six pitot tubes (designated rake F). These were mounted on a collar attached to the shaft ahead of the struts as shown in Figures 31 and 32. The collar contained bronze bearings, so that the shaft would rotate while the

rakes were held fixed. It was determined early in the trial that the bronze bearings were wearing out. Therefore, they were removed and replaced with water-lubricated cutless bearings. Collar movement was controlled by two wire cables, which were led around a drum on the collar up to a winch installed on the deck. A close-up view of the control cables is shown in Figure 33. The deck was marked with lines and a pointer was attached to the cable on the deck. As the pointer moved between the lines, it indicated the angular positions of the rakes as the winch rotated them around the shaft. Pressure lines from the pitot tubes were wrapped around the collar under the cable drum, and were then led up the outboard strut inside a faired conduit as shown in Figure 33. It was thus possible to control the tension on the tubing from the deck whenever the angle of the rake was changed.

The conduit for the boundary layer probes was run along the bottom of the ship from the region aft of the attachment targets to the transom of the ship as shown in Figure 27, and from there to the deck as noted in Figure 7. To install the boundary layer probes, divers removed plugs from the ends of the conduit, and attached the pressure tubes to a line connected to the plugs. The pressure tubes were then pulled through the conduit to the deck with these lines. Once they were in place, divers bolted the boundary layer probes to the bottom of the ship, and adjusted the angles of the probes, which were operative as soon as they were connected to the pressure gauges.

Eight boundary layer probes were used. Probes 1 and 8 were 138.8 feet (42.3 m) aft of the forward perpendicular and one foot (0.3 m) outboard of the propeller shaft centerline. Probes 2 and 6 were 118.25 feet (36. m) aft of the forward perpendicular and on the shaft centerline, immediately forward of the propeller shaft stern tube bossing. Probe 6 was actually destroyed in a high-speed turning maneuver before any data were recorded. Probes 3, 4, 5, and 7 were located near the transom, 154.9 feet (47.2 m) aft of the forward perpendicular. Probes 3 and 7 were located three feet (0.9 m) outboard of the ship centerline on the starboard and portsides, respectively. Probes 4 and 5 were located one foot (0.3 m) outboard of the ship centerline on the starboard and portside, respectively.

The piezoelectric pitot tube was mounted on the port side shaft rake in the same manner as the other pitot tubes. However, instead of having the pressure lines and electrical connections internal to the rake as in the pneumatic system, the tubing was run down the face of the rake and through the front of the cable drum. Pressure leads were then led up the conduit to the deck in the same manner as the other tubing.

FULL-SCALE TRIAL MEASUREMENTS

The entire agenda for the series of full-scale trials is presented in Table 1. Two separate propeller disk wake surveys were performed, followed by an experiment to measure boundary layer velocity profiles, and an experiment to attempt to measure time-varying pressures ahead of an operating propeller.

The trials were run in the Atlantic Ocean off the mouth of the St. Johns River near Jacksonville, Florida from 4 September through 13 September 1977. Environmental conditions throughout the trial were considered excellent, with light winds and calm seas prevailing. Observations were recorded at 0800 EDT each day prior to runs, and wind and sea conditions during runs were recorded in the bridge log. Table 2 presents the trial conditions for the four experiments. Water temperature was measured at approximately 1500 EDT each day when the ship was standing still for a rake angle change. Ship drafts were read before and after each day's run, with the only significant change occurring on 8 September.

Ship course was maintained with small rudder angles of between two and five degrees with a mean of approximately 2.5 degrees left rudder. Rudder angle was never varied during data collection. A mini-ranger tracking system was used during some early runs to determine the yaw angles of the ship. During run 16, for example, the steered course was shown on the graph as 90 degrees from the horizontal line (which represents the mini-rangers' base course) as shown in Figure 34. A mean line through the track for run 16 shows that the ship's path deviated approximately one degree from the steered course which is in the vertical direction on Figure 34. This implies a one-degree yaw angle, which is acceptable

for obtaining accurate measurements and maintaining a stable course. Later, in run 25, the track indicated three degrees of yaw angle as noted in Figure 35, which was the highest recorded during the trial. Yaw angles for all high-speed runs averaged one degree, due to better course-keeping ability at higher speeds.

Roll and pitch angles of the ship throughout the trials were consistently small, in most cases less than three degrees. During Experiment 3, in which boundary layer measurements were taken, the roll and pitch were less than one degree due to the extremely calm conditions prevailing. Appendix A summarizes the visual data observed from the ship instrumentation on the bridge for each run number. The data were observer averages of the values obtained during a run which typically lasted about 10 minutes. No bridge data were obtained for Runs 12 through 15.

Experiment 1 of the trials agenda was designed to measure the difference in the wake with and without an operating propeller. One plane of measurement was on the starboard shaft, forward of the propeller disk, and one plane was on the port shaft (which had the operating propeller) at the same axial location. Experiment 1 was performed at two speeds, corresponding to speeds attainable under diesel power or gas turbine power. The diesel-powered surveys were accomplished first to insure that data would be obtained even if the system did not function properly at higher speeds. When a limited number of data points had been obtained at the diesel-powered speed, the speed was increased and gas-turbine power utilized. The shaft torque meter was used to be sure that torque limits on shafting and gears were not exceeded. A speed of 15.1 knots (7.77 m/s) was established as safe and adequate for project purposes.

Experiment 2 was performed to measure the wake in an exact duplication of the technique used in wake surveys conducted at model-scale. In preparation for this experiment, divers removed the rakes and pitot tubes from the forward plane of the starboard shaft and the pitot tubes from the rakes on the port shaft. The experiment was run entirely in the turbine mode and the speed which was achieved was 15.3 knots (7.87 m/s), since drag was reduced when instrumentation was removed.

Experiment 3 measured eight boundary layer velocity profiles. Divers installed boundary layer rakes symmetrically on both the port and starboard sides. Measurements taken from the total head tubes were referenced to the static head at the tube farthest from the hull surface, since it was found that this static head gave the most consistently accurate results.

Experiment 4 involved a pioneering attempt to measure the time-varying velocities ahead of the operating propeller. The piezoelectric pitot tube was installed at the third radial position from the shaft, on the port shaft rake ahead of the propeller.

Several problems associated with the installation of the piezoelectric system resulted in the failure of two out of five transducers. First, the transducers were very fragile, and one could not be zeroed nor could its sensitivity be adjusted when it was linked to the signal conditioning equipment. Second, since the ship was not drydocked between experiments, it was impossible to keep the piezoelectric system completely dry. Water apparently damaged another transducer and its signal was also lost. Despite this initial system failure, measurements were made with the operative components to determine if such a system would be useful for future research.

Experiment 4 was run both diesel and turbine-powered with the port side rake set at three different angles. Pressures were measured from the three functional transducers. In addition, a time-dependent signal was displayed on an oscilloscope. Pressure fluctuations within one revolution of a propeller blade were observed; however, their magnitude was insignificant and little could be ascertained from these measurements other than that the system appeared to work acceptably.

PRESENTATION OF RESULTS

EXPERIMENT 1 - WAKE SURVEY WITH AND WITHOUT A PROPELLER

The data for the forward plane of the starboard shaft without a propeller at the two speeds of Experiment 1 are presented in Figures 36, 37, and 38. These data are presented to illustrate any effect due to speed on the results. The data which were taken at the lower speed of 8.95 knots* (4.60 m/s) show more scatter than the data obtained at the higher speed of 15.1 knots* (7.77 m/s). The greater amount of scatter is attributed to the fact that the pressures which were measured were much lower at the lower speed. Small errors in pressure measurement thereby cause a larger percentage error in the low speed velocity component data. It should be noted, however, that the values of velocity component ratios from both speeds of Experiment 1 are reasonably consistent. The notable exception is the radial velocity component shown in Figure 38 between 280 and 360 degrees where a significant difference occurred. This difference is most probably due to measurement error, such as a blocked or open pneumatic tube.

The second part of Experiment 1 was run in the turbine mode at speeds up to 15.1 knots* (7.77 m/s). This part of the experiment was intended to provide a comparison of velocity components ahead of the propeller disk,

* Speeds are average values of speeds measured by the towed knotmeter during the individual runs.

with and without the propeller operating. Figures 39, 40, and 41 show velocity component data plotted as a function of angular position for the starboard shaft (no propeller) and port shaft (propeller). When the scatter in values is taken into consideration, it is not possible to discern any significant difference between the two sets of data. In particular, the mean longitudinal velocity for both port and starboard disks varies only minutely. The velocity component ratios for the two parts of Experiment 1 are presented in tabular form in Appendix B.

EXPERIMENT 2 - WAKE SURVEY CORRELATING WITH MODEL DATA

Experiment 2 was performed to provide full-scale data for correlation with model towing tank wake survey data. The plane of measurement was as close as possible to the propeller plane on the starboard shaft. The measurements were made in four radial positions, using pitot-tube rakes A and B. The radii of measurement were 0.456, 0.633, 0.781, and 0.963 times the propeller radius, corresponding to the same positions as the model five-hole pitot tubes in Rake 6.

The velocity component ratios computed from ship and model data measured in the starboard propeller plane are presented in Figures 42 through 45. These data correspond to the data which are taken in the normal procedure in the model towing tank. Appendix C presents the velocity component ratios for Experiment 2 in tabular form.

In considering agreement with model data, the accuracy and repeatability of the full-scale experiments must be taken into account. Based on results from repeated full-scale runs, the data shown for the longitudinal velocity component ratios are considered to be accurate to within $\pm$ 0.10, while the tangential and radial component data are considered

accurate to within $\pm$ 0.05. Angles were measured and referenced against a check with a spirit level in drydock, and are considered to be accurate to within plus or minus two degrees. The speed of the ship was measured with a towed knotmeter with accuracy to within $\pm$ 0.2 knots ($\pm$ .10 m/s).

EXPERIMENT 3 - BOUNDARY LAYER VELOCITY PROFILES

Following the propeller disk wake survey, the boundary layer velocity profile rakes were installed by divers at the pier of the Mayport Naval Station, and Experiment 3 was conducted. Total head measurements were referenced to static pressure measurements taken on the outermost tube of the rake.

Data were gathered at four speeds during the boundary layer profile measurements. These speeds varied from the lowest speed at which control could be maintained, 6.3 knots* (3.22 m/s), to the speed at which the torque limit was reached on the propelling shaft, 16.6 knots* (8.53 m/s). The other speeds of 9.1 knots* (4.68 m/s) and 14.8 knots* (7.61 m/s) were attempts to duplicate speeds employed for measurement of the wake. Tabulated data taken at four speeds during Experiment 3 are presented in Appendix D. The boundary layer data for the wake measurement speed of 14.8 knots (7.61 m/s) have been plotted as a function of normal distance from the hull, as shown in Figures 46 through 52, and have been non-dimensionalized by ship speed for a more conventional presentation in Figures 53 through 59. A composite plot, Figure 60, for the data taken at various speeds for boundary layer rake position 1, clearly shows the effect of speed on the boundary layer velocity profile.

EXPERIMENT 4 - TIME-VARYING PRESSURE MEASUREMENT

Experiment 4 was undertaken to measure time-dependent pressures ahead of a propeller using piezoelectric pressure gauges on the head of the

pitot tube. Despite difficulties with two of the five transducers, it was decided that attempts should be made to measure time-dependent pressures with the piezoelectric system, and to compare values obtained with pneumatic measurements. Appendix E presents the mean pressure data for Experiment 4 at several angular positions in the plane ahead of the propeller.

Data were sampled from the piezoelectric transducers at every six degrees of propeller shaft rotation. These samples were taken over periods of five to ten minutes during steady running conditions with shaft rotational speeds of 240 and 345 rpm. Figures 61, 62, 63, and 64 present the pressures for each angular position of all five pressure transducers as averaged for runs 205 and 209 at 345 rpm and run 208 at 240 rpm. As mentioned before, the outermost radial (R2) and center (C) transducers failed to function. It is interesting to note that the three operating gauges show the same 16-cycle variation, which was exhibited on the oscilloscope trace. In particular, the data from gauge R1 shown in Figure 62 and the oscilloscope trace shown in Figure 65 exhibits very similar behavior. The apparent consistency between this relatively long-time average signal and the oscilloscope trace lends credence to the conclusion that there was indeed a varying pressure measured by these gauges, and that it varied at two and four times the blade rate frequency.

The output from one of the pressure gauges was displayed on an oscilloscope during the runs. A photograph of the oscilloscope trace is shown in Figure 65. The upper trace shows the external synchronization with one revolution of the propeller, while the lower trace shows the pressure gauge reading during the same revolution. The propeller was rotating at approximately 345 rpm during the run. From the measurements taken, it was determined that signal oscillation was on the order of one

percent of the average reading. The frequency appears to be approximately 16 times the shaft rotational frequency, or four times blade rate. The validity of absolute values are questionable, however, since it was not possible to calibrate the system prior to taking measurements. It is possible that the piezoelectric pressure gauges were merely acting as accelerometers in measuring time-varying values.

These data show that time-varying pressure measurements can be made using such a piezoelectric system, and that it can serve as an acceptable alternative to the pneumatic system. More attention, however, needs to be paid to signal conditioning and to waterproofing transducers if time-varying velocities are to be determined with an acceptable degree of accuracy.

DISCUSSION OF RESULTS

A review of the results presented in this report shows that, in general, project goals were met and significant information was developed relative to the state-of-the art for full-scale wake surveys. All three components of velocity, both in the propeller disk and ahead of the propeller disk, were successfully measured with and without the propeller in operation. Sufficient data were obtained to determine a ship-model correlation of wake.

The data from pitot tubes in the two planes forward of the propeller reveals that there is little significant difference between measurements made on the shaft of the operating propeller and measurements made on the shaft after the propeller blades have been removed. This lack of propeller effect may be partially due to the position of the plane of measurement, which is approximately one diameter ahead of the propeller.

The data from model experiments agree with the full-scale measurements reasonably well for the outer radii. The large differences in longitudinal velocity component in the innermost radius is most probably due to difficulties measuring model velocities in the vicinity of the large propeller hub, which is at a significant angle to the flow due to shaft angle. A more detailed investigation of this particular scale effect is proposed in a research and development project concerning the appendage resistance of surface ships. The full-scale data reported herein make such an investigation possible.

The differences between full-scale and model-scale measurements of the tangential velocity components are also larger for the innermost radius measured. The model experiments were performed in several ways, including free-to-trim, fixed in trim at the full-scale condition, with and without the port propeller operating, and even in shallow water representing the actual depth of water during the full-scale trial. None of these variations made significant improvement in the correlation of the tangential velocity components. The primary contribution to the tangential velocity component of the wake appears to be the obliquity of the shaft to the flow, which, from these data, appears to be mainly upward from the bottom of the hull.

The wake measured in the propeller plane on the starboard shaft shows smaller effects from the shaft struts than had been measured on the corresponding model. This finding is most probably due to the fact that the wake of the shaft struts is narrower full-scale than model scale, and the fact that full-scale measurements were made at wider angular increments than the model measurements.

Boundary layer velocity profiles were obtained at several locations on the hull. These data show that there is little difference in velocity profile structure, regardless of whether the propeller is operating or not. The profile measured at Location 2 is significantly lower than the others. One possible explanation for the lower values of velocity measured at Location 2 is the nearness of the propeller shaft stern tube, which penetrated the hull surface immediately aft of the boundary layer rake. A comparison of the data from Location 6 would have added weight to this argument, however, the boundary layer rake at Location 6 was lost in a high-speed turn before any data was taken. Model measurements of the velocity profiles have been made in a wind tunnel using hot wire anemometers. The velocity profiles measured at Location 2 on the model did not show lower values than at other locations.

The piezoelectric measurements were partially successful. Time-varying pressures were measured on three of the five gauges. Significant variations of pressure can be measured at two and four times the blade rate frequency. These frequency-dependent measurements are long-time averages of data, and, therefore, considered significant. However, their cause is uncertain at this time.

ADDITIONAL WORK

Model correlation experiments were run to determine differences in velocity component ratios. An experiment was run with a 1:8.25-scale model of the R/V ATHENA at speeds corresponding to Froude-scaled speeds of the full-scale trial, and at the highest speed which can be obtained practically on the towing carriage. In addition, an experiment with a double-hulled model in the wind tunnel was conducted to measure boundary layer profiles at model-scale Reynolds numbers. Velocities ahead of a model-

scale operating propeller were also measured in the wind tunnel. The results of these experiments will be presented in more detail in other DTNSRDC reports.

The wake survey data reported herein may be used in calculating full-scale alternating and time-average propeller loads for the controllable-pitch propeller on the R/V ATHENA. Additional full-scale trials have been performed to measure these alternating propeller loads. Furthermore, model experiments have been performed with the 1:8.25-scale model of the R/V ATHENA to measure the same alternating propeller loads. The validation of the calculation procedures at both model and full-scale is made possible by the existence of the full-scale and model-scale wake data.

In addition to the propeller load calculation, the wake data and boundary layer data from the full-scale R/V ATHENA may be used in a calculation of full-scale appendage drag. The critical unknown parameter in any calculation of the drag of an appendage is the inflow velocity to that appendage. With the use of the R/V ATHENA wake data, a more accurate representation can be made of the flow into the shafts, struts, and rudders of the full-scale ship. Hence, calculations of full-scale appendage drag can be made with more confidence. Such full-scale information will then be useful in correlating model and full scale measurements of appendage drag.

It appears that the piezoelectric pitot tube is an instrument with good potential for measuring time-dependent velocities of the flow near an operating propeller. Therefore, it is recommended that further effort be put into the development of the piezoelectric pitot tube system, and continuing evaluation be made of its applicability to time-dependent

velocity measurement. It may well be proved that such a system will be of great value in those full-scale environments where pneumatic tubing and gauges do not perform adequately.

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The authors are especially appreciative of the untiring efforts of Al Yoder, Zeke Fulcher, Ray Franklin, Frank Collyer, and the rest of the R/V ATHENA crew in preparing and operating the vessel.

Vern Phelps and Armin Troesch of the University of Michigan developed the instrumentation, and John Hackett and Dale Fiekema of the University provided assistance in monitoring instrumentation during the trial.

Last but not least, the authors thank Marilyn Dick of CHI ASSOCIATES, INC. for her assistance in sorting and analyzing the mass of data which resulted from the trial.

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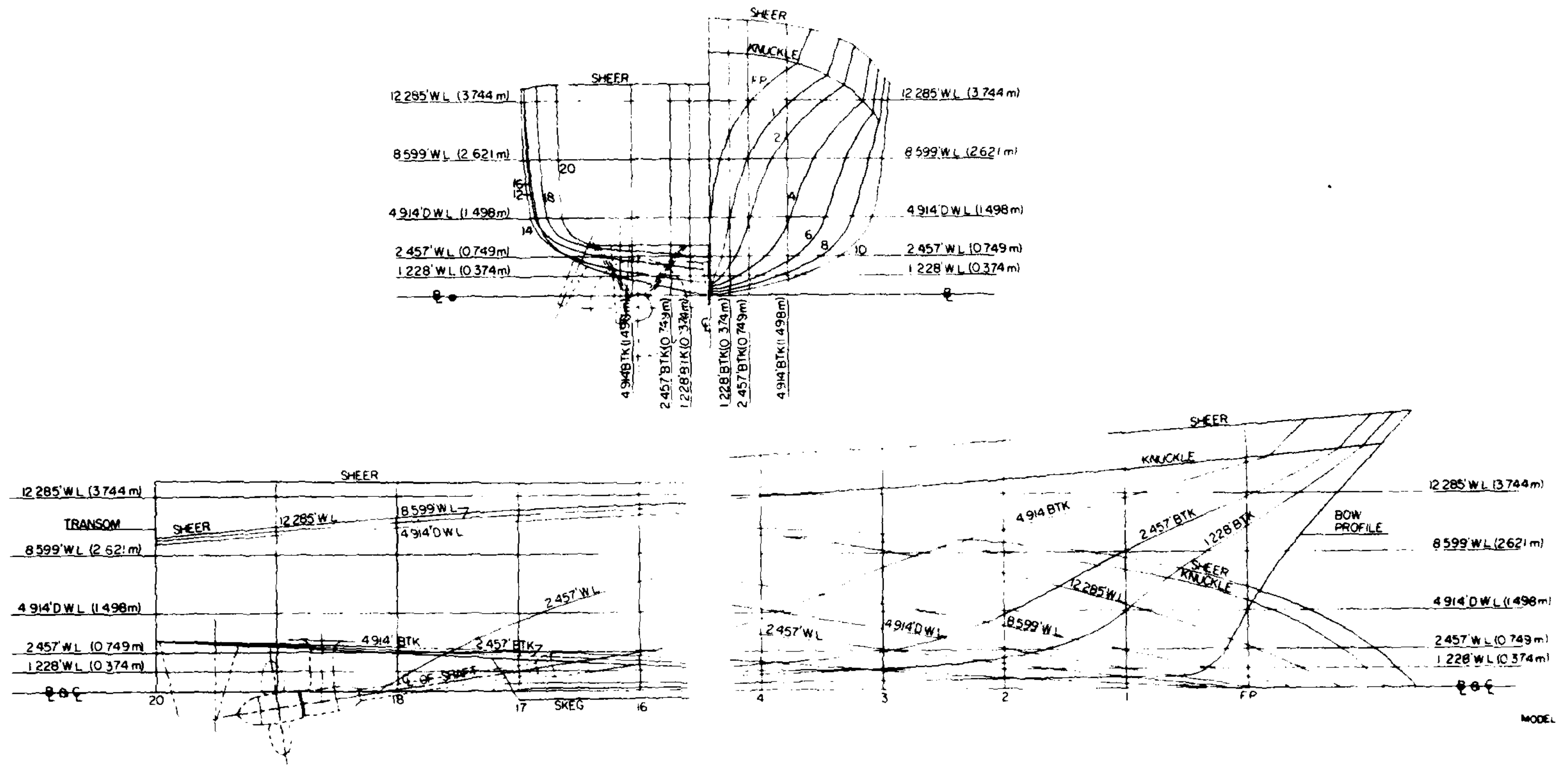


Figure 1 - Ship Lines for R/V ATHENA

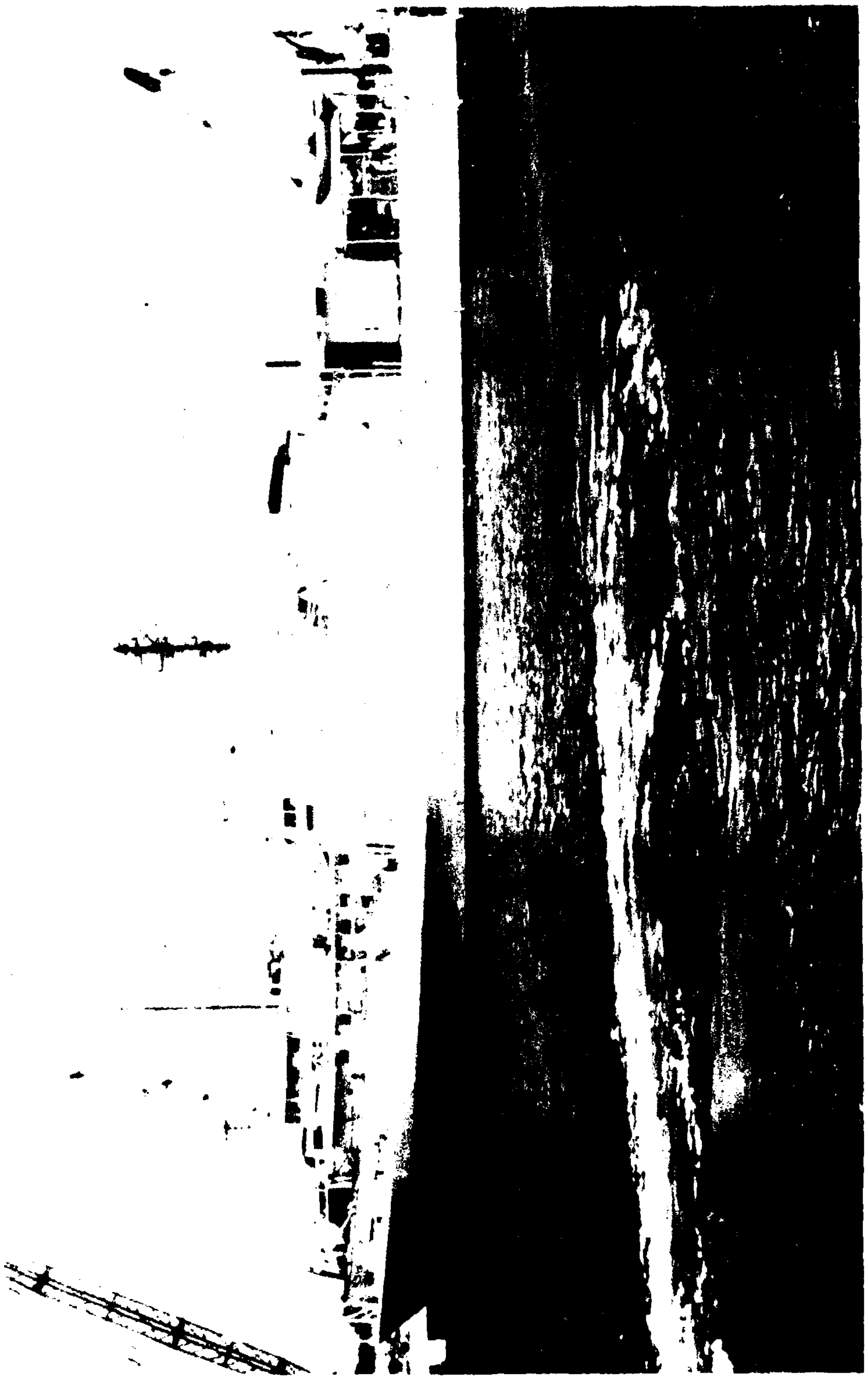


Figure 2 - The R/V ATHENA

Figure 3 - Controllable-Reversible Pitch Propeller on Port Shaft on R/V ATHENA

Figure 4 - Bow Quartering View of R/V ATHENA on Drydock

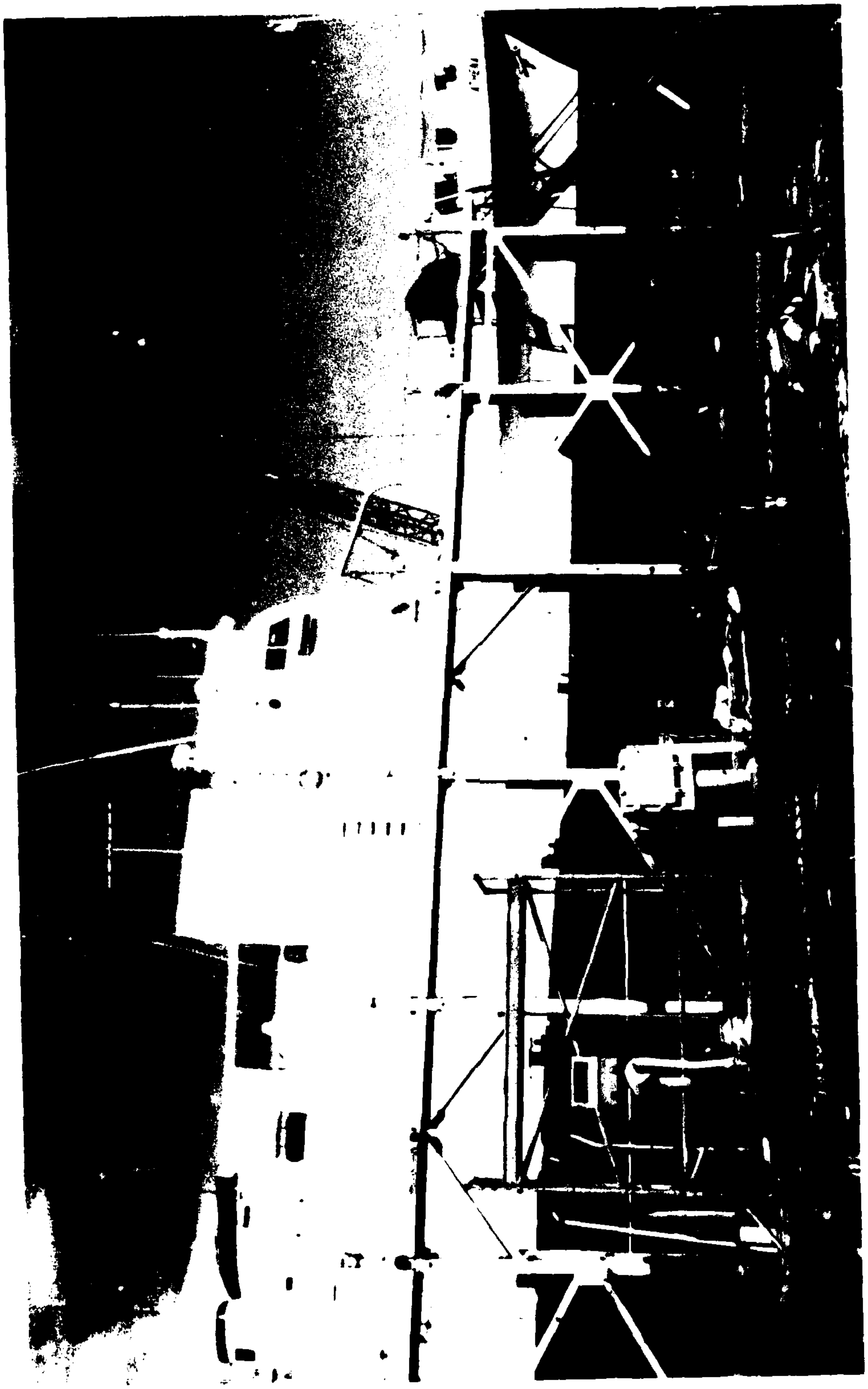
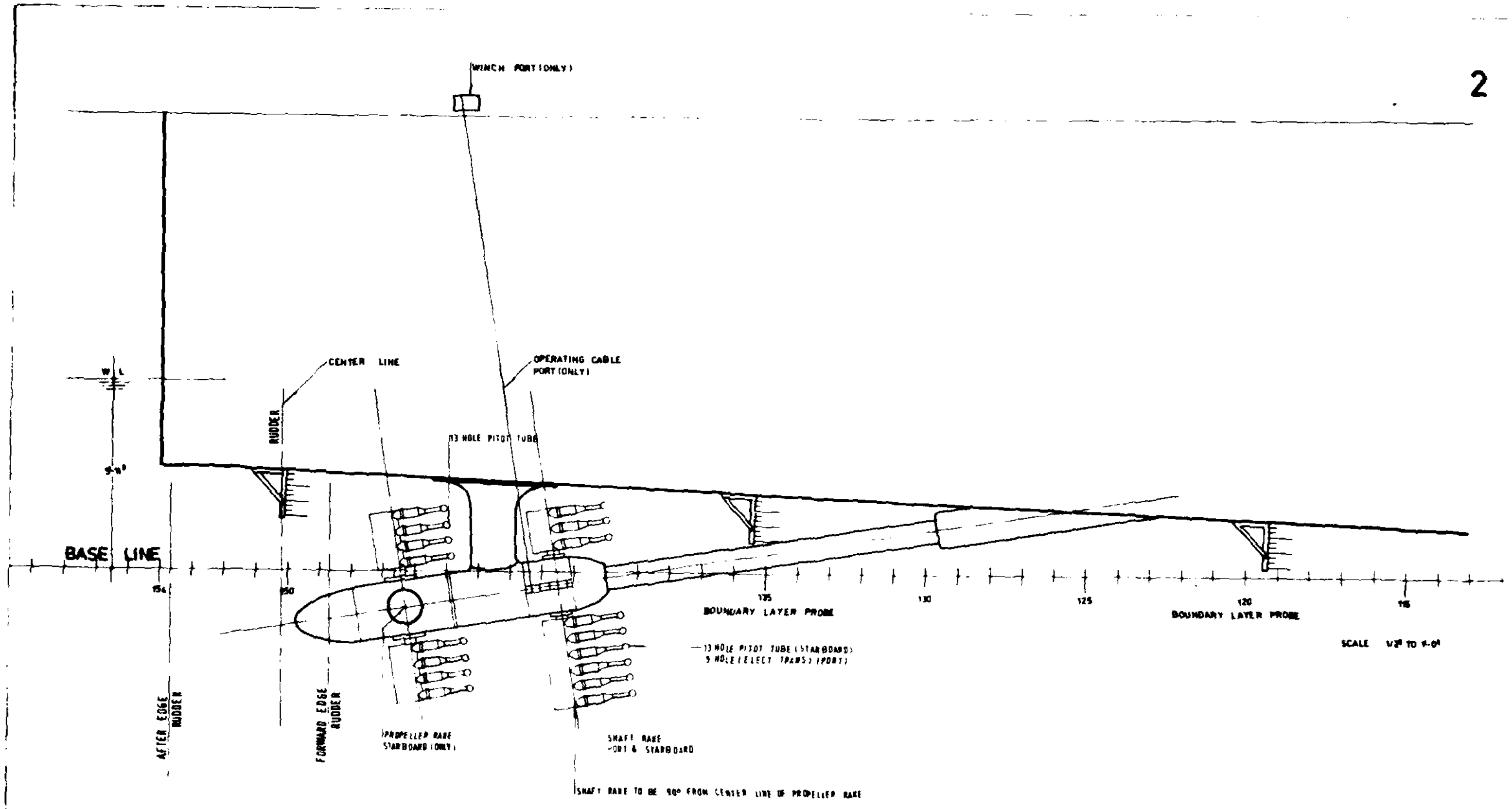


Figure 5 - Broadside View of R/V ATHENA on Drydock



NOTE: ALL PITOT TUBES 5 HOLES UNLESS NOTED.

Figure 6 - Profile View of Hull Showing Installation of Wake Rakes and Boundary Layer Rakes

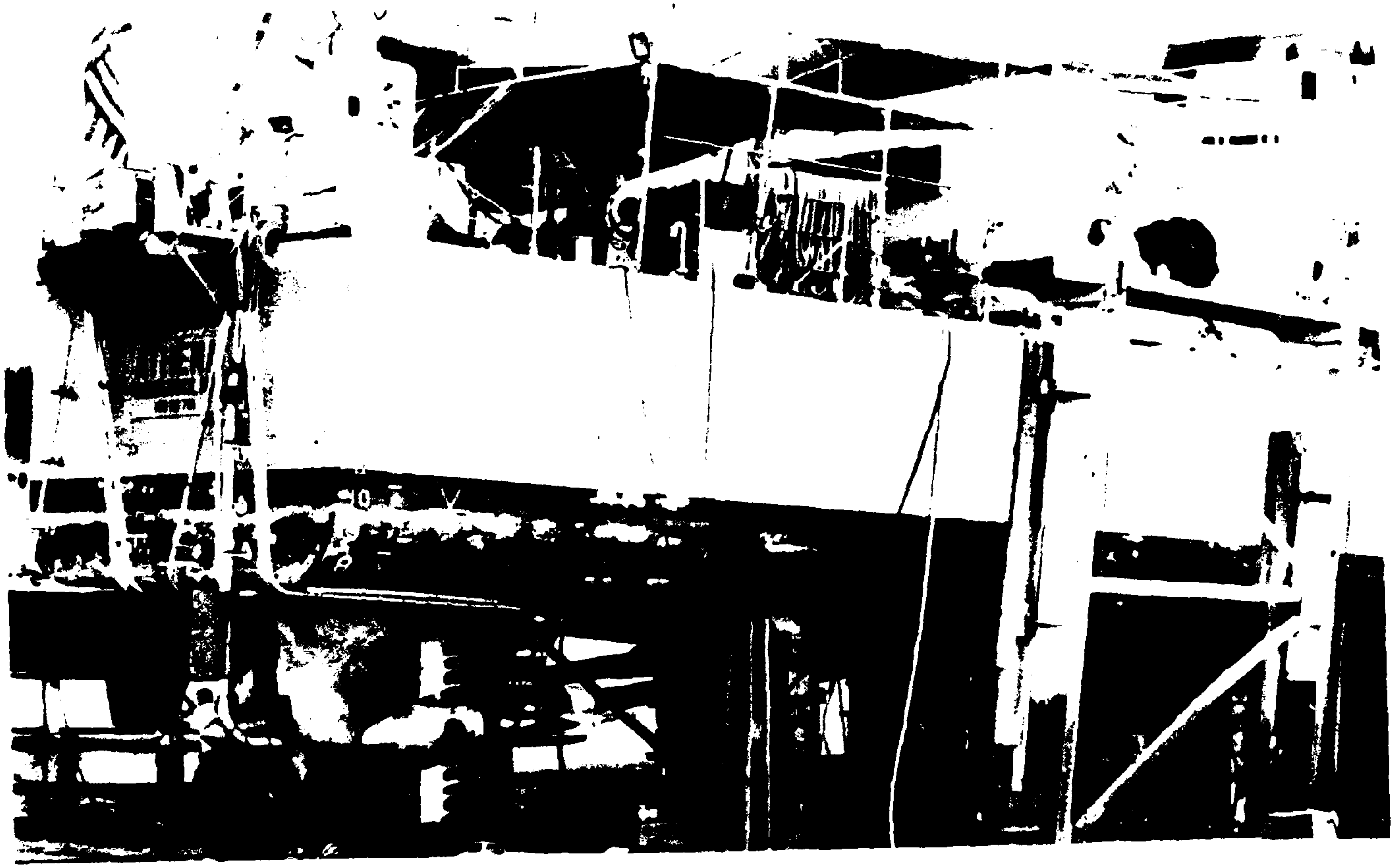


Figure 7 - Stern Quartering View of R/V ATHENA on Drydock Showing the Arrangement of Piping for the Pressure Tubing

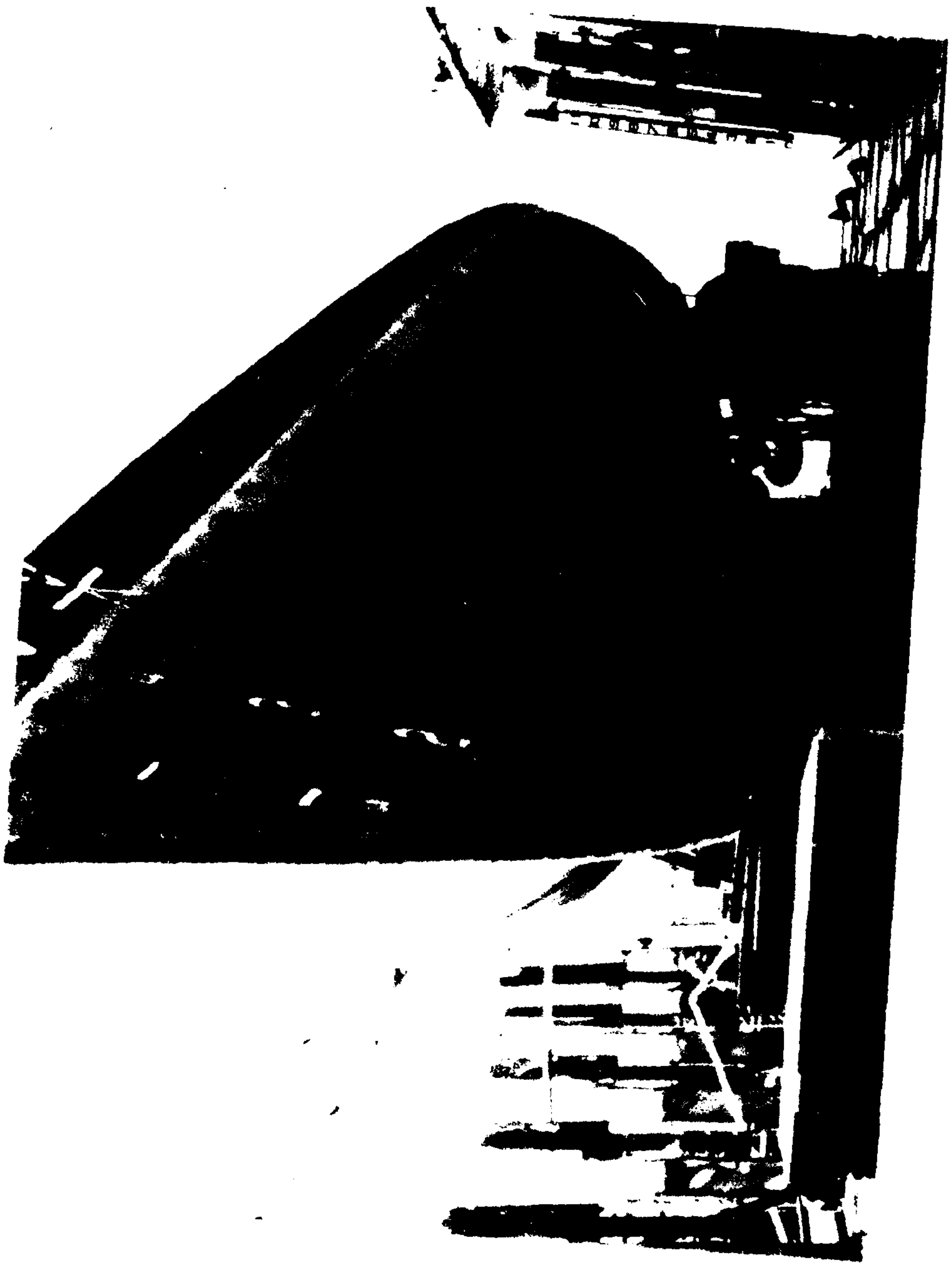


Figure 8 - Bow View of R/V ATHENA at [illegible]

Figure 9 - Model 4950-1 in Circulating Water Channel of DTNSRDC for Flow Visualization Study (Side View)

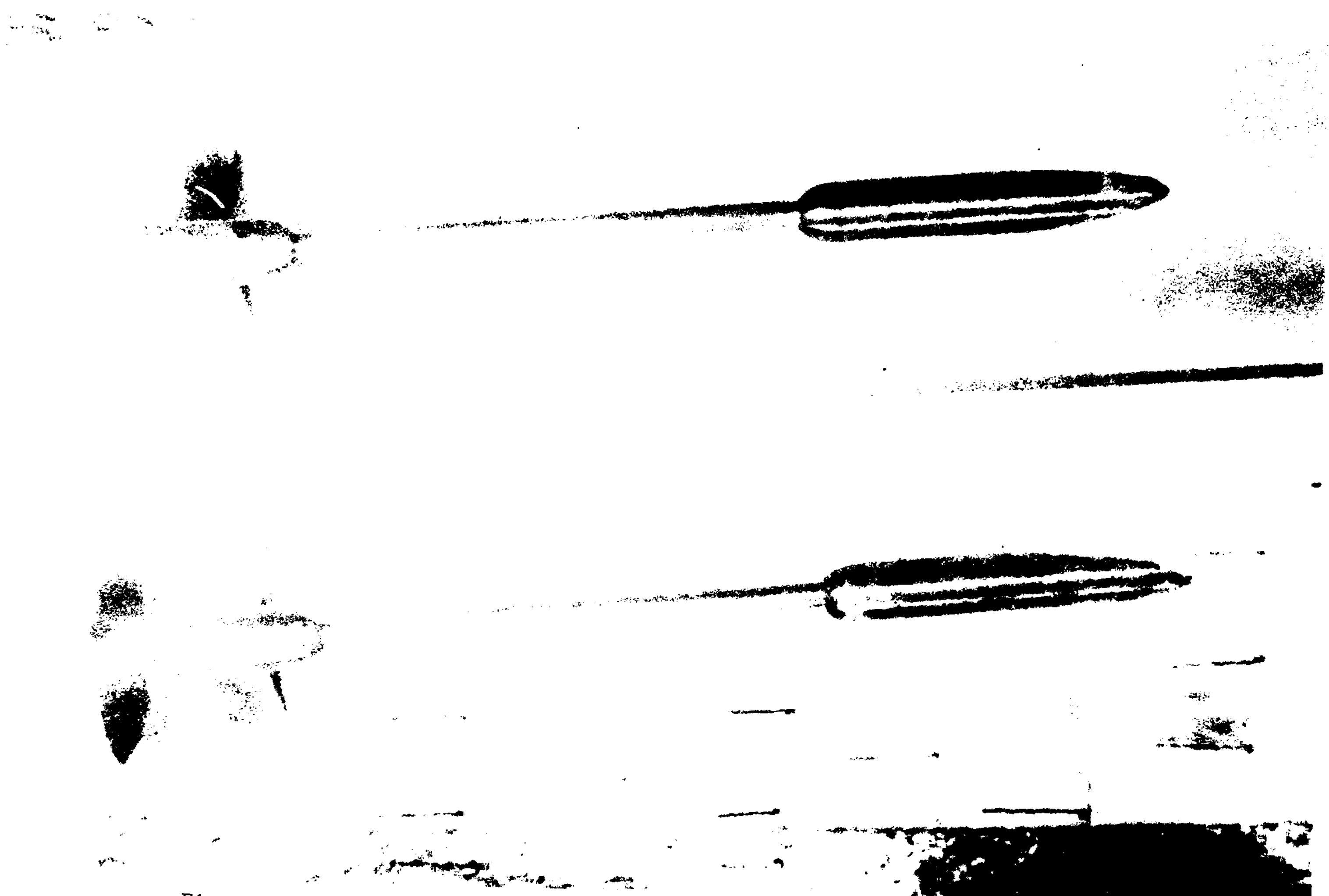


Figure 10 - Model 4950-1 in Circulating Water Channel of DTNSRDC for Flow Visualization Study (Bottom View)

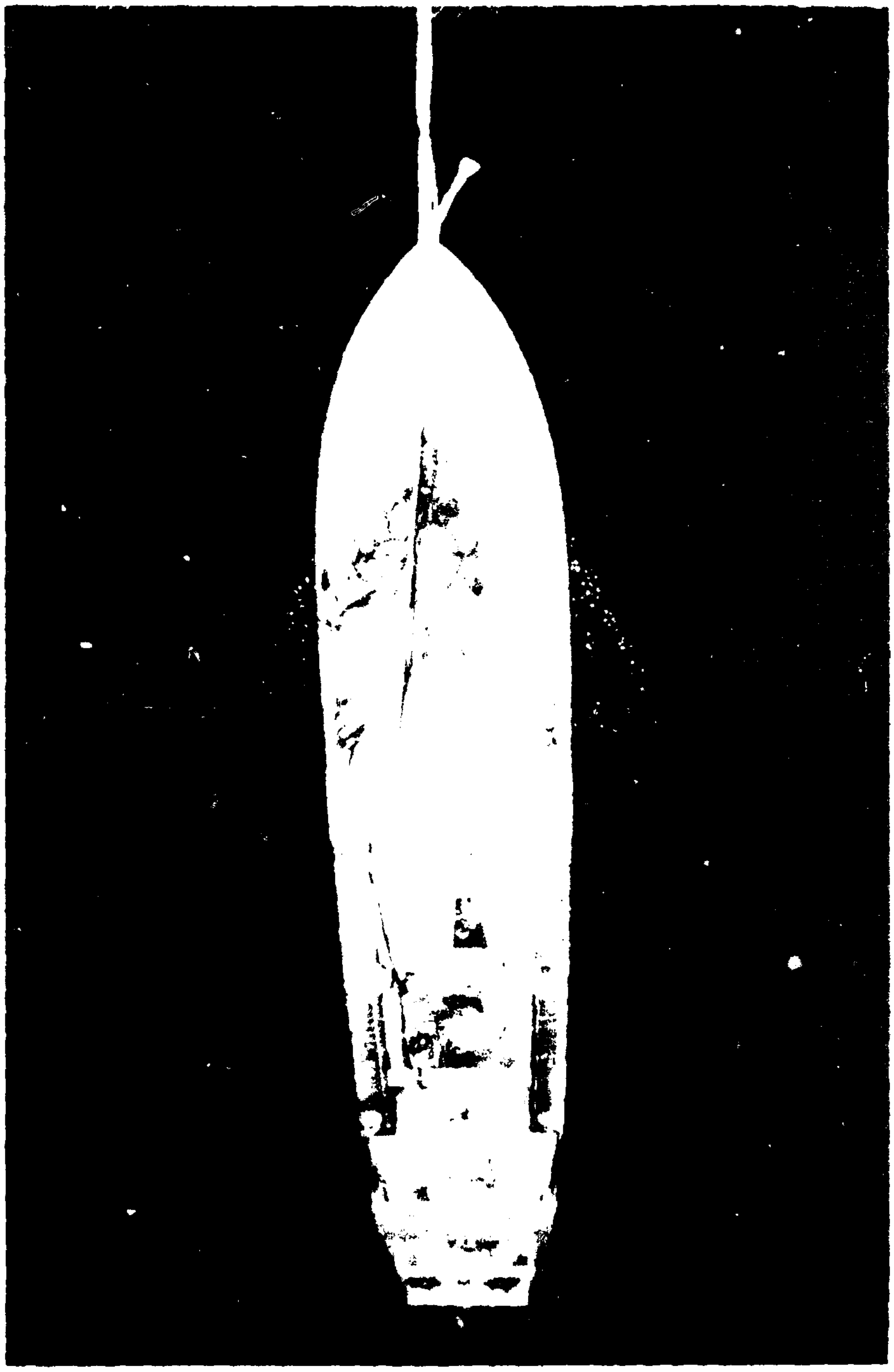


Figure 11 - Model 4950-1 Self-Propelled by Port Shaft Only (Aerial View)

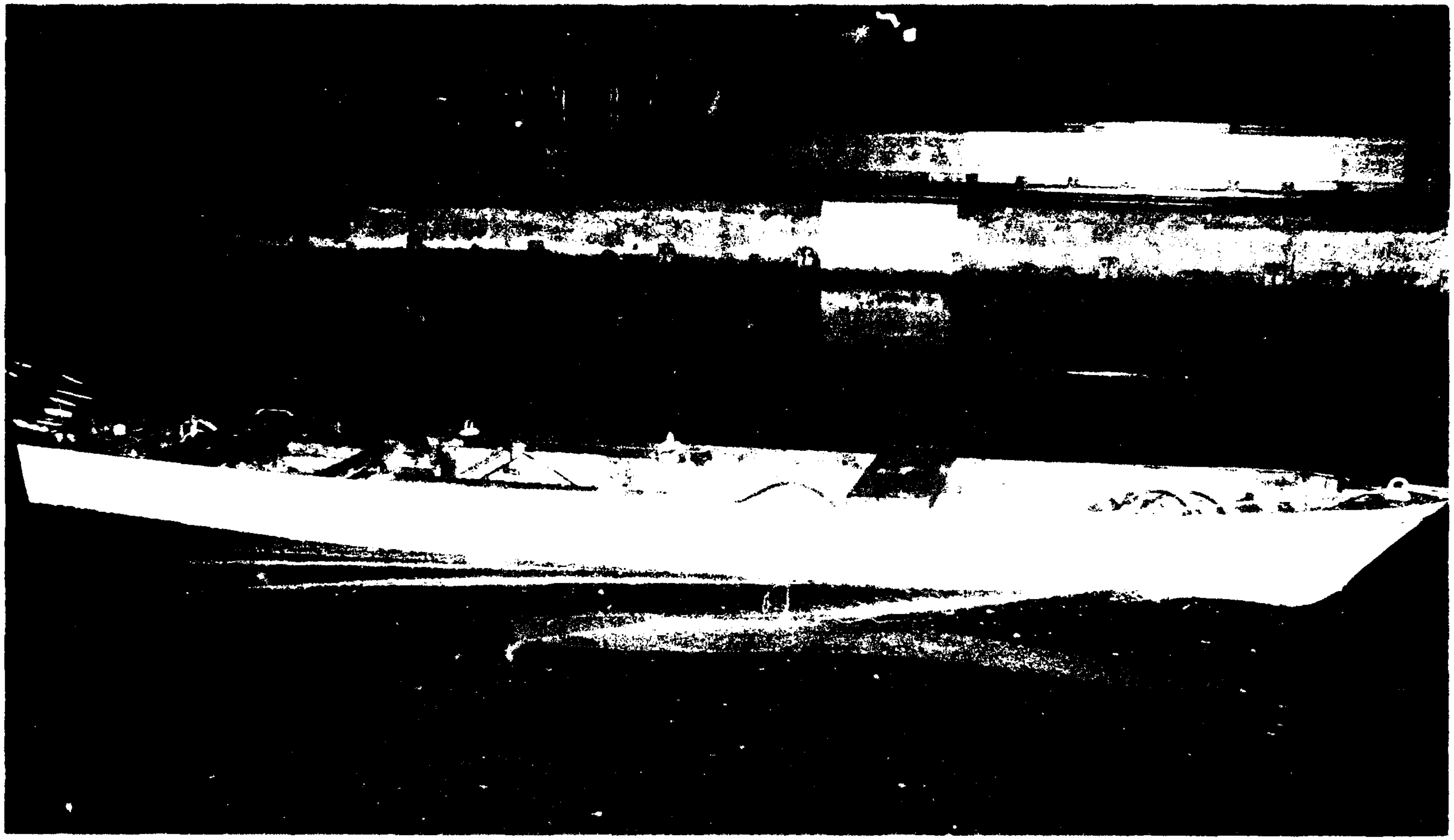
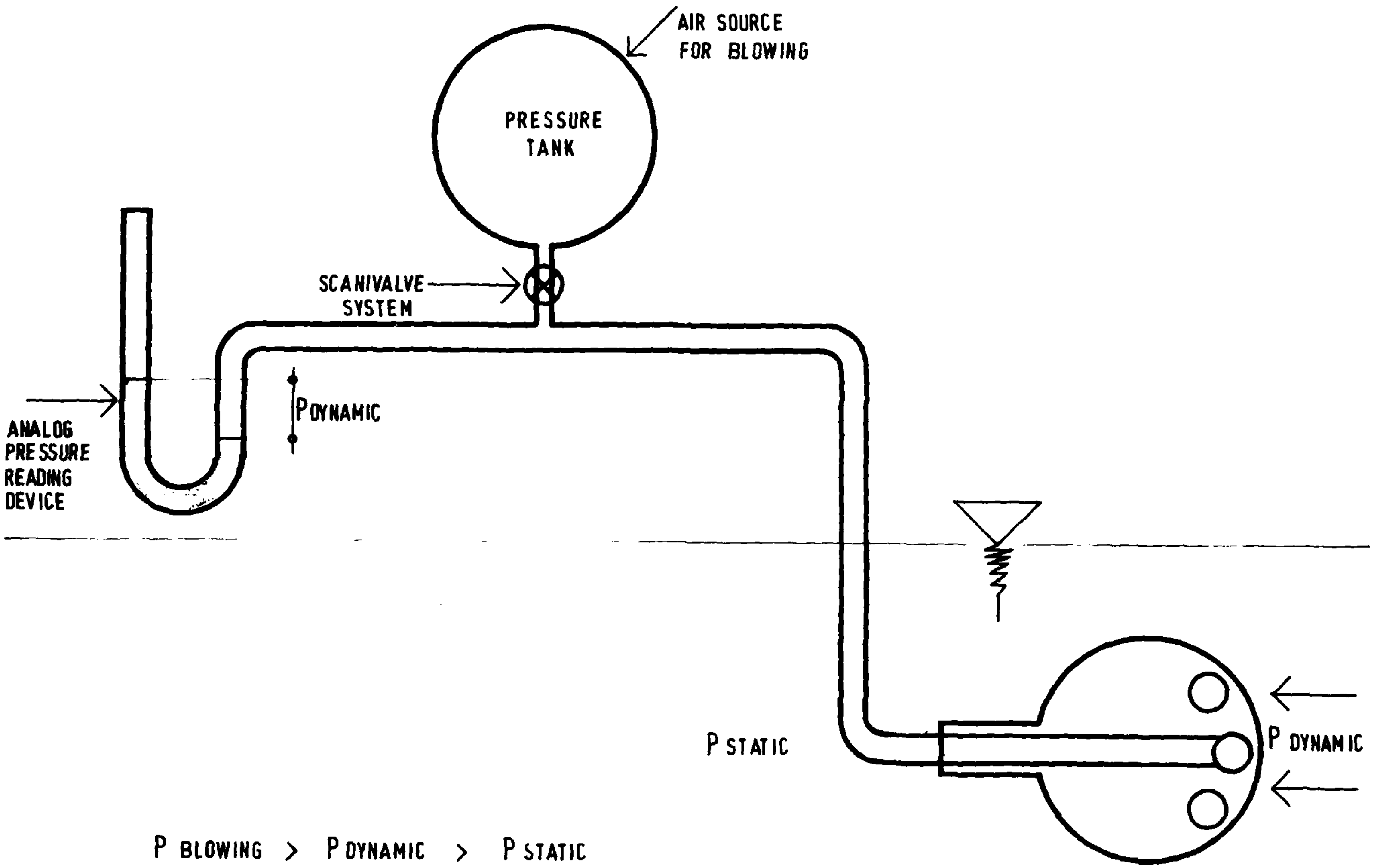


Figure 12 - Model 4950-1 Self-Propelled by Port Shaft Only (Side View)



$P_{BLOWING} > P_{DYNAMIC} > P_{STATIC}$

Figure 13 - Schematic of Scanivalve Pneumatic System

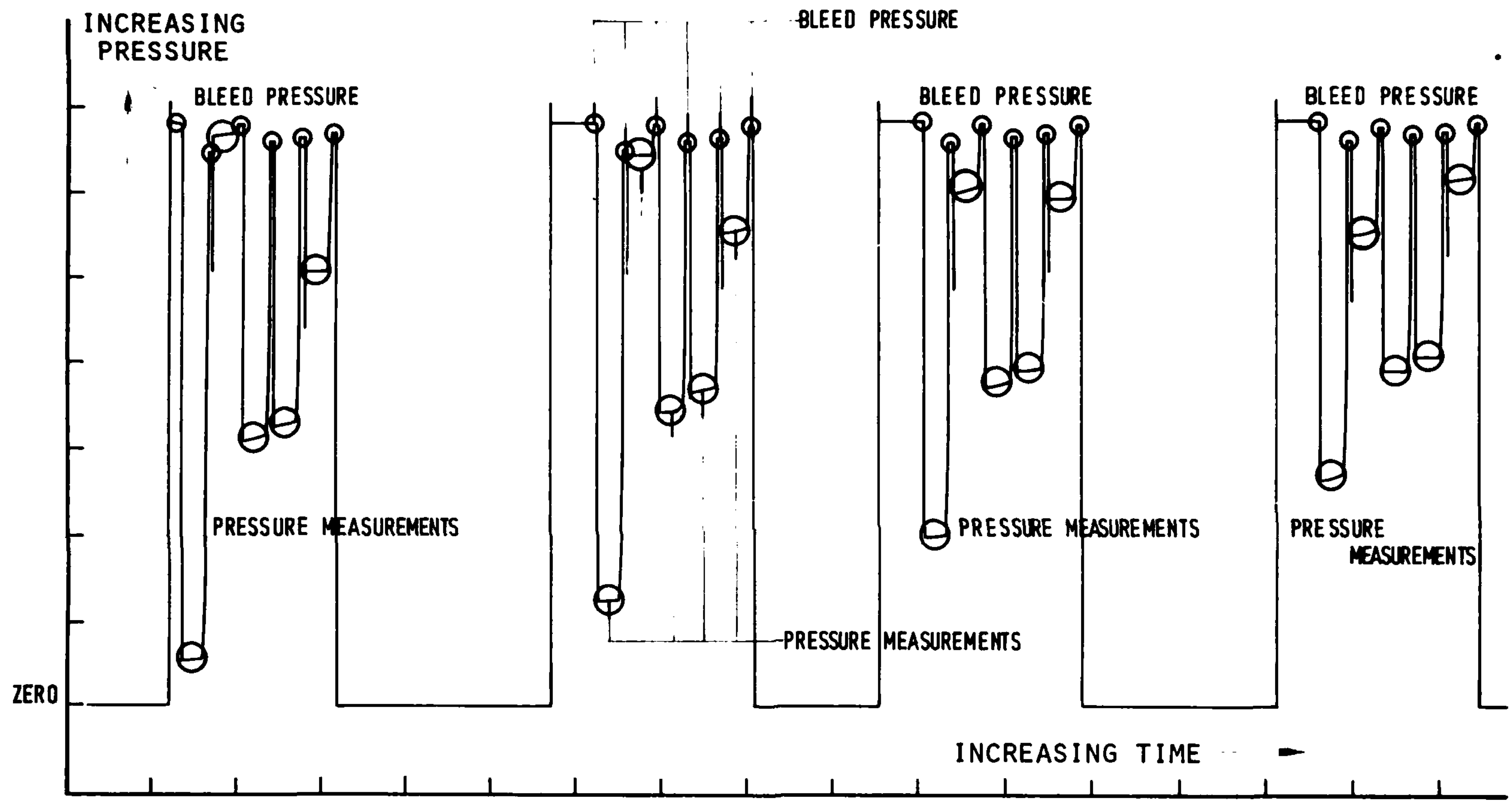


Figure 14 - Strip Chart Recording of Pressures Taken During Tow Tank Calibration of 5-Hole Spherical Pitot Tube

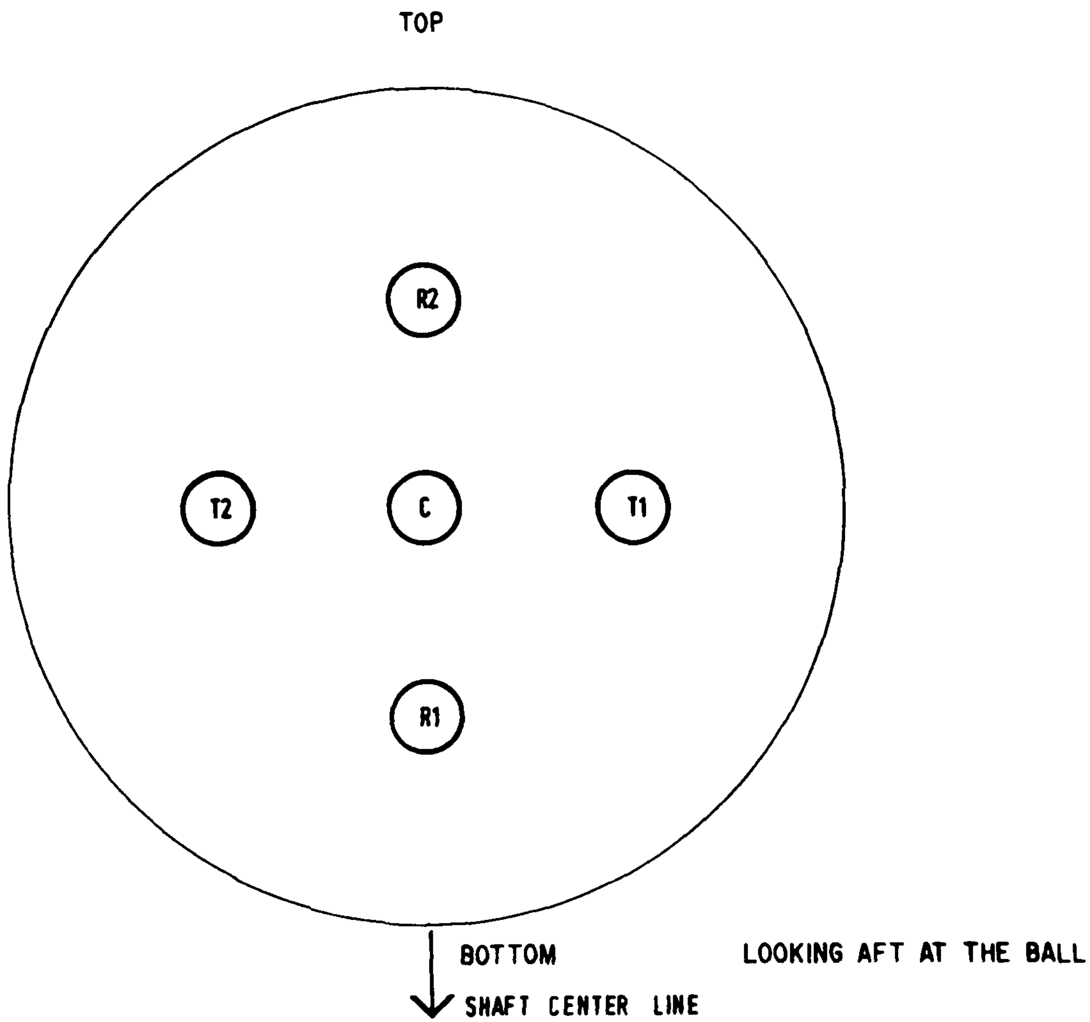


Figure 15 - Schematic of 5-Hole Pitot Tube

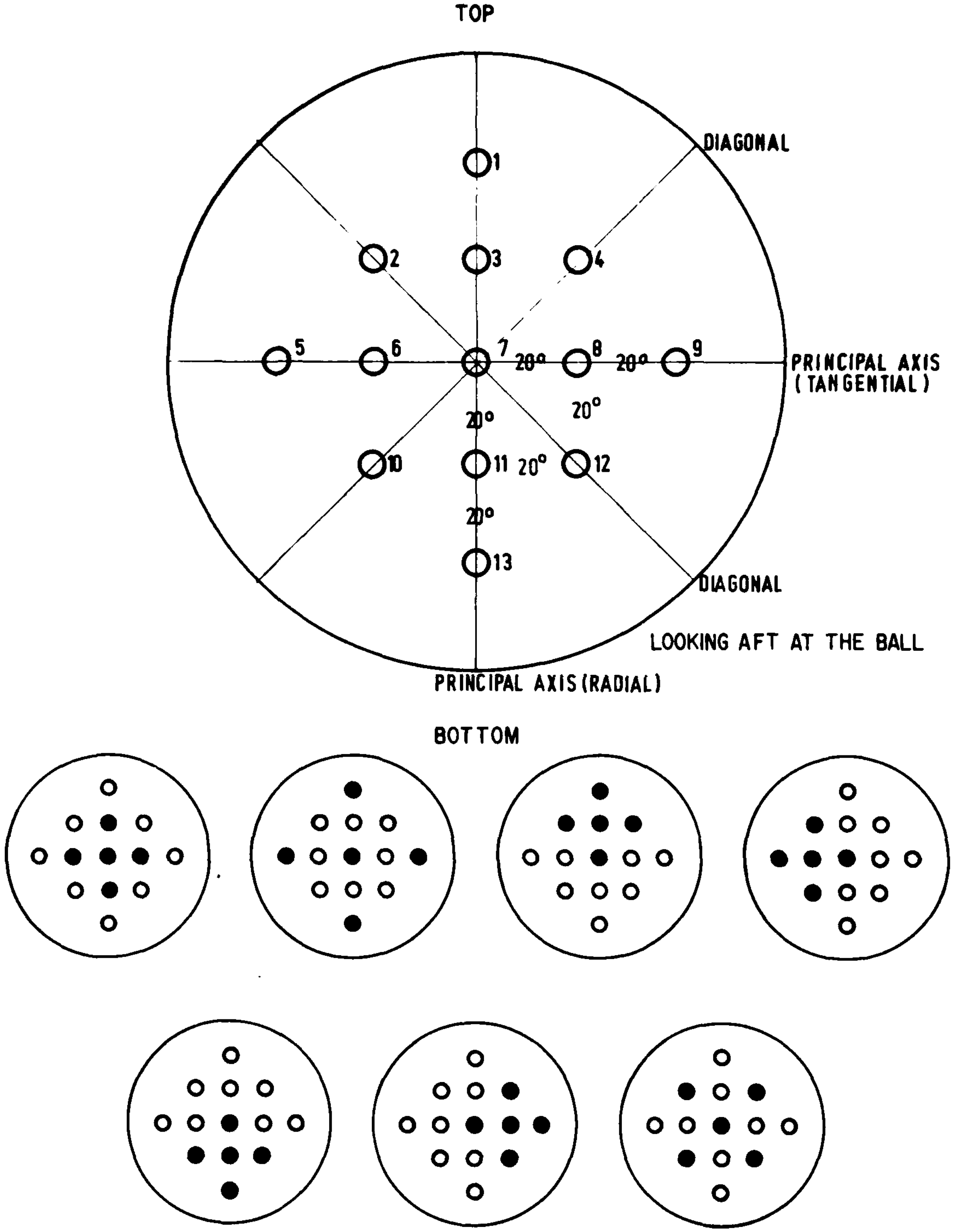


Figure 16 - Schematic of 13-Hole Pitot Tube

Figure 17 - Lucite Construction Model of 13-Hole Spherical Pitot Tube (Two Views)

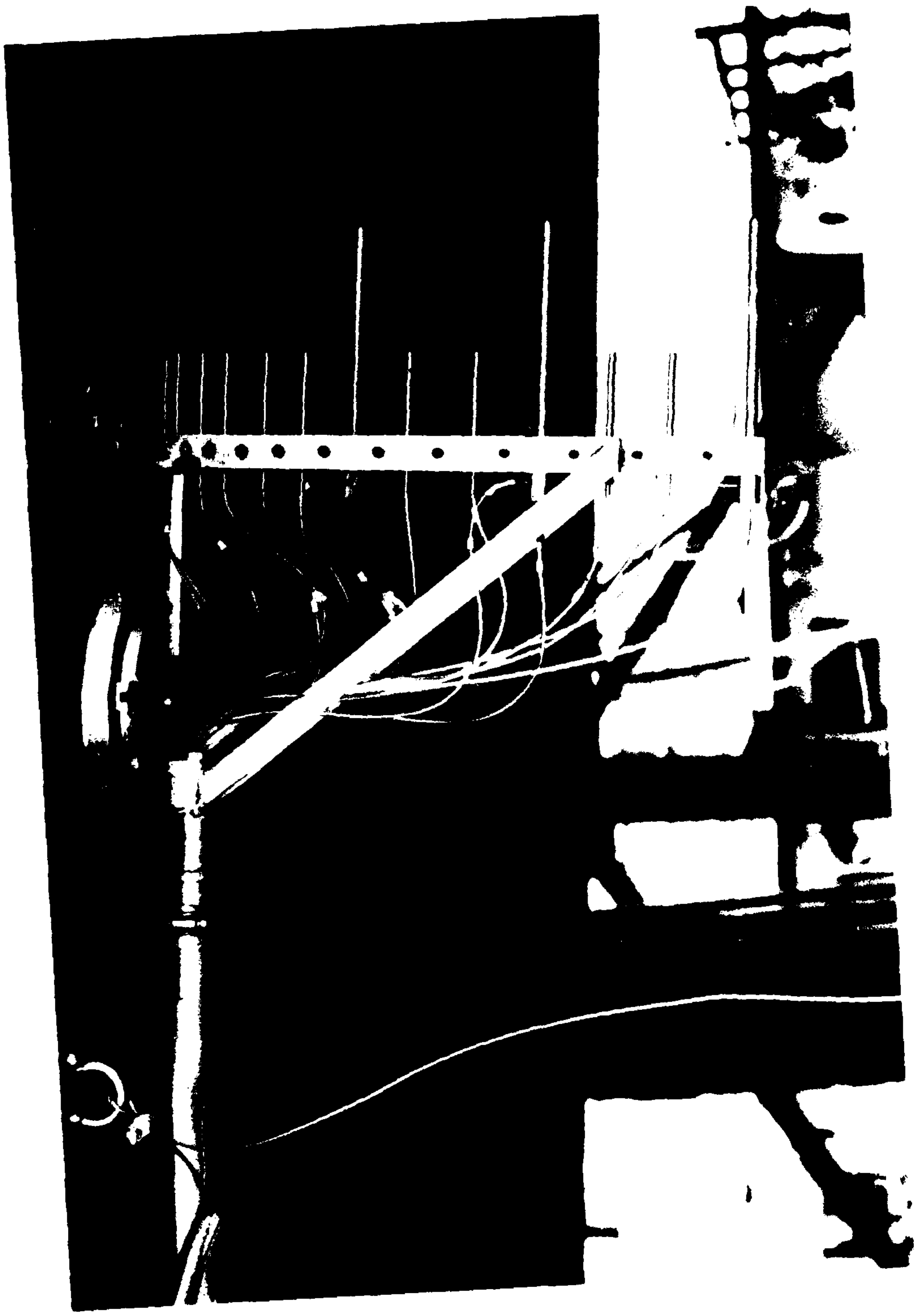


Figure 18 - Boundary Layer Pressure Tube Rake

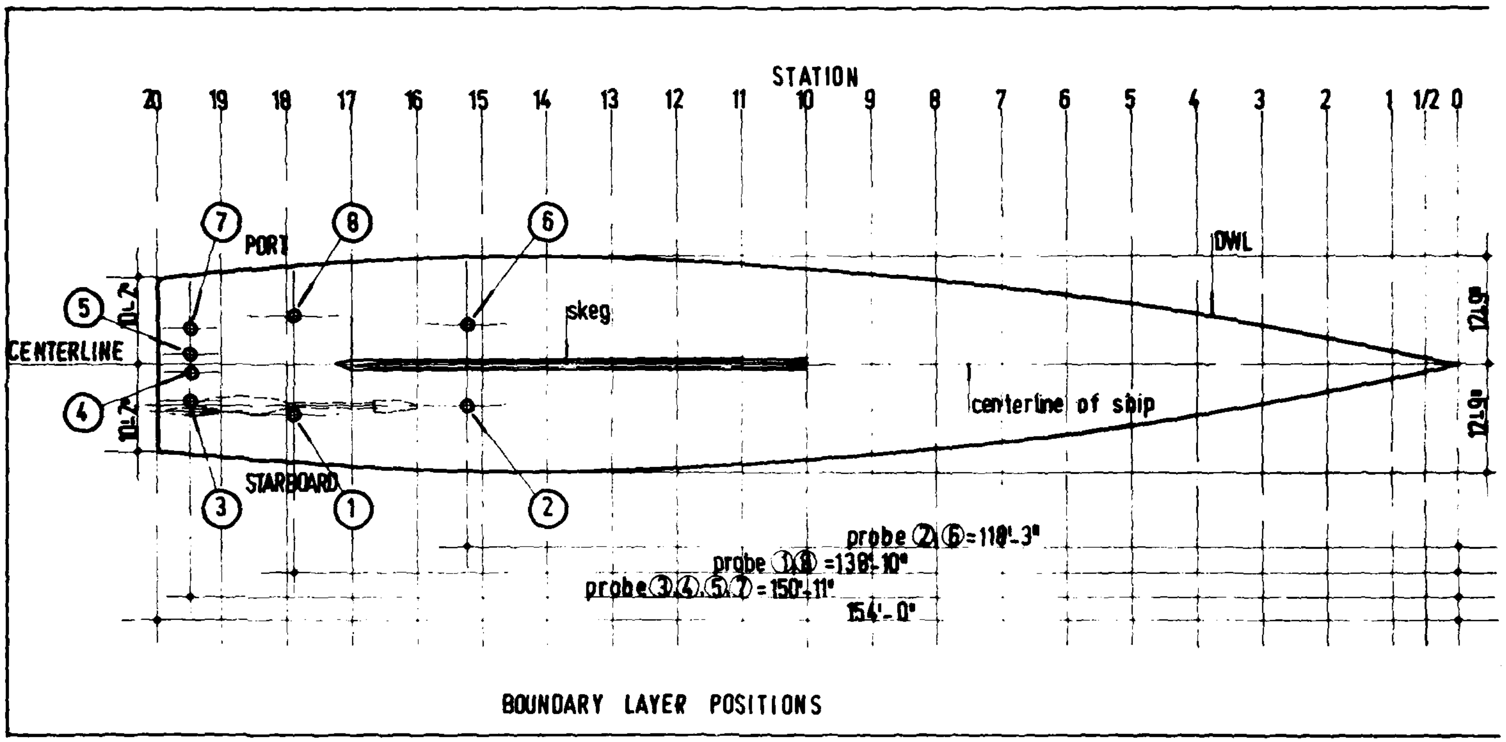


Figure 19 - Plan View of Hull Showing Boundary Layer Rake Locations

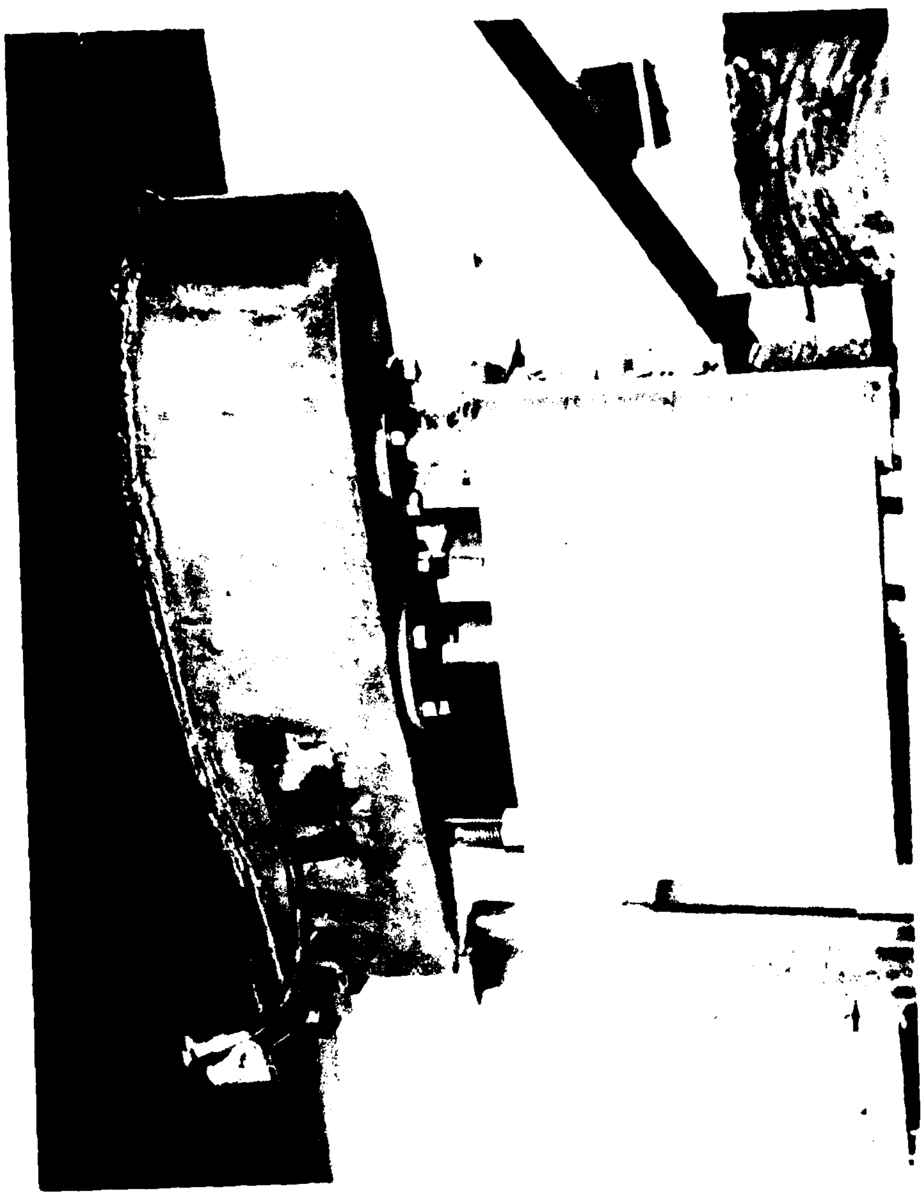


Figure 20 - Keel Mounted Yaw Meter

Figure 21 - Air Bleed During Pitot Tube Calibration in Tow Tank

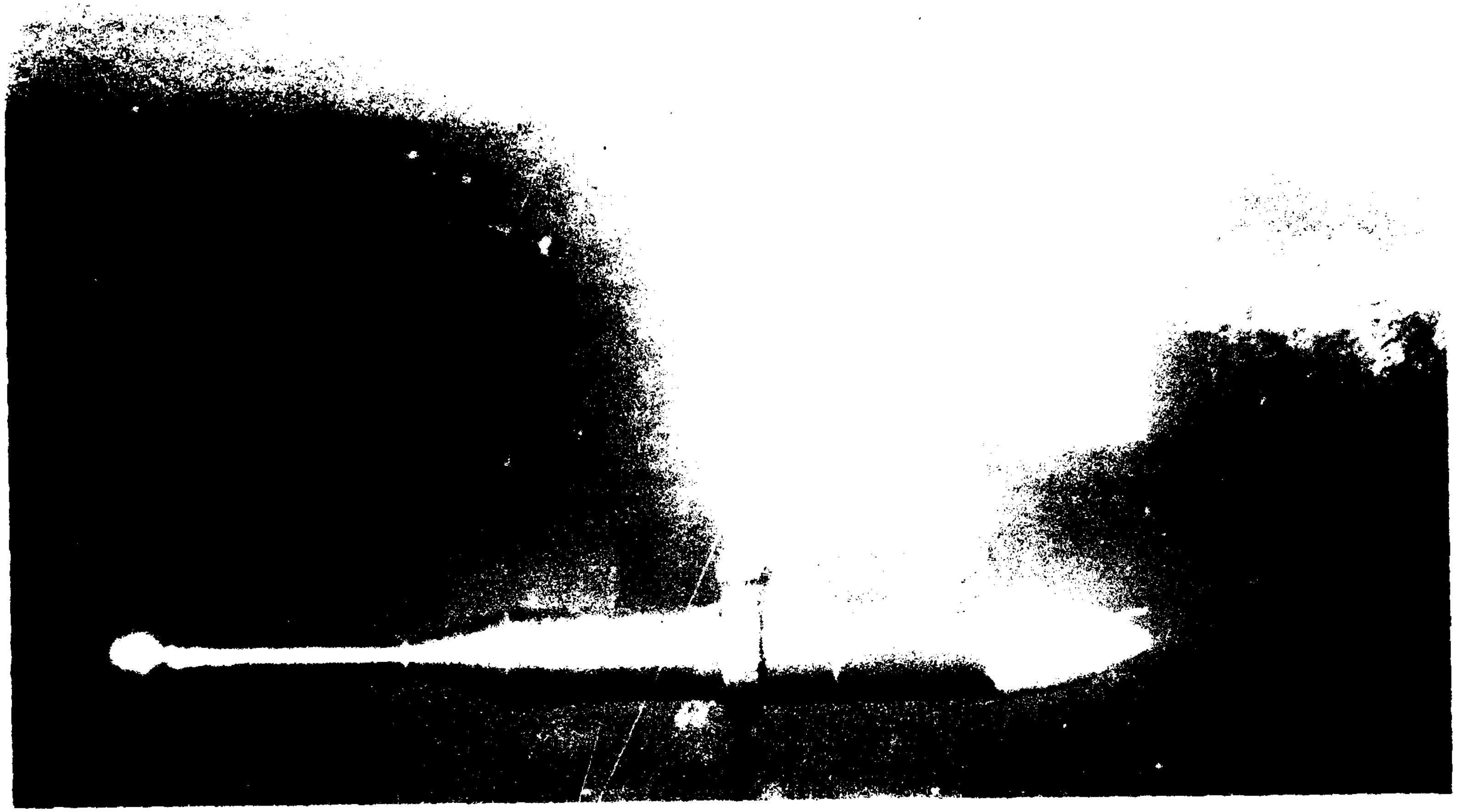


Figure 22 - Measuring Cycle of Pitot Tube in Tow Tank

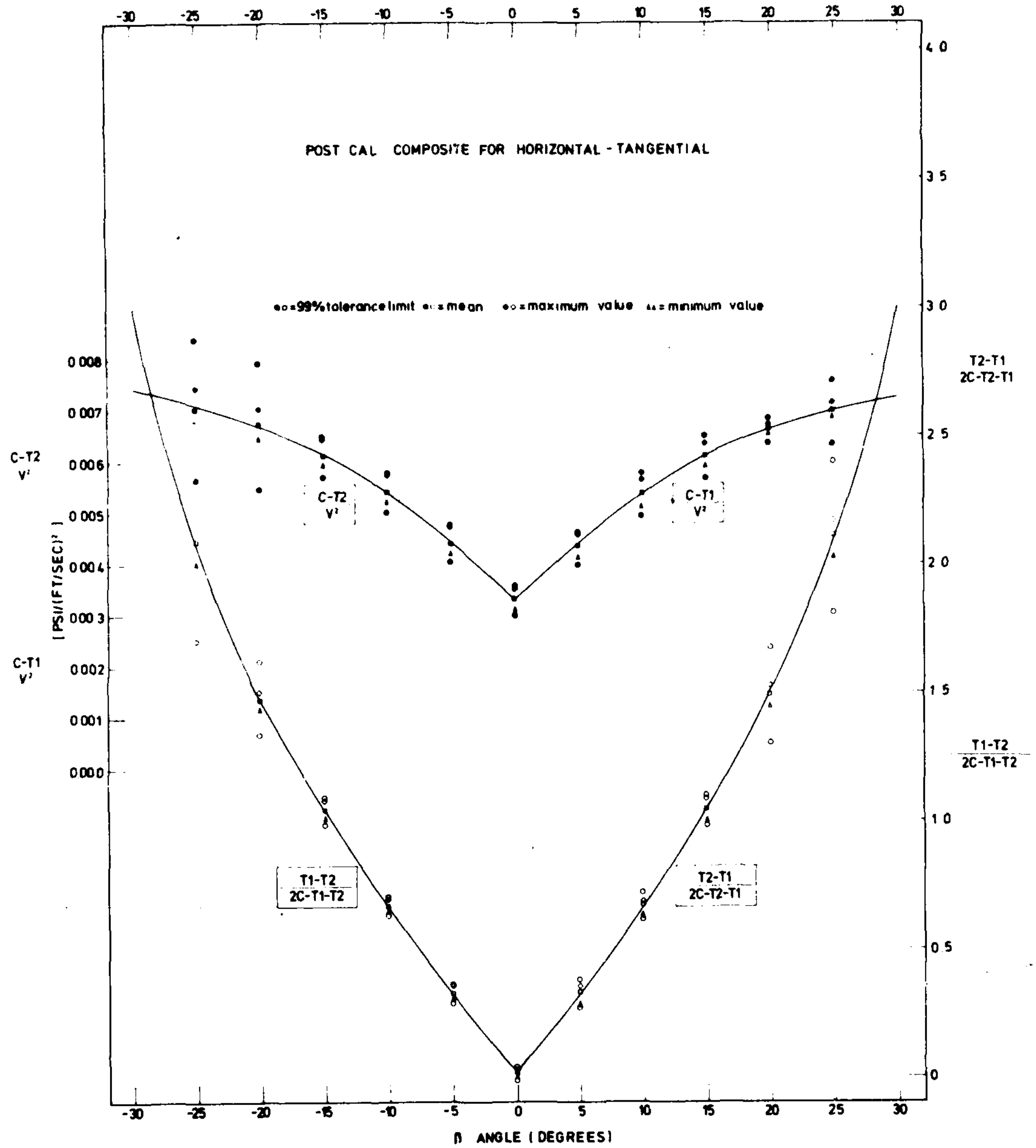


Figure 23 - Composite Plot of 5-Hole Pitot Tube Calibrations in the Horizontal-Tangential Plane

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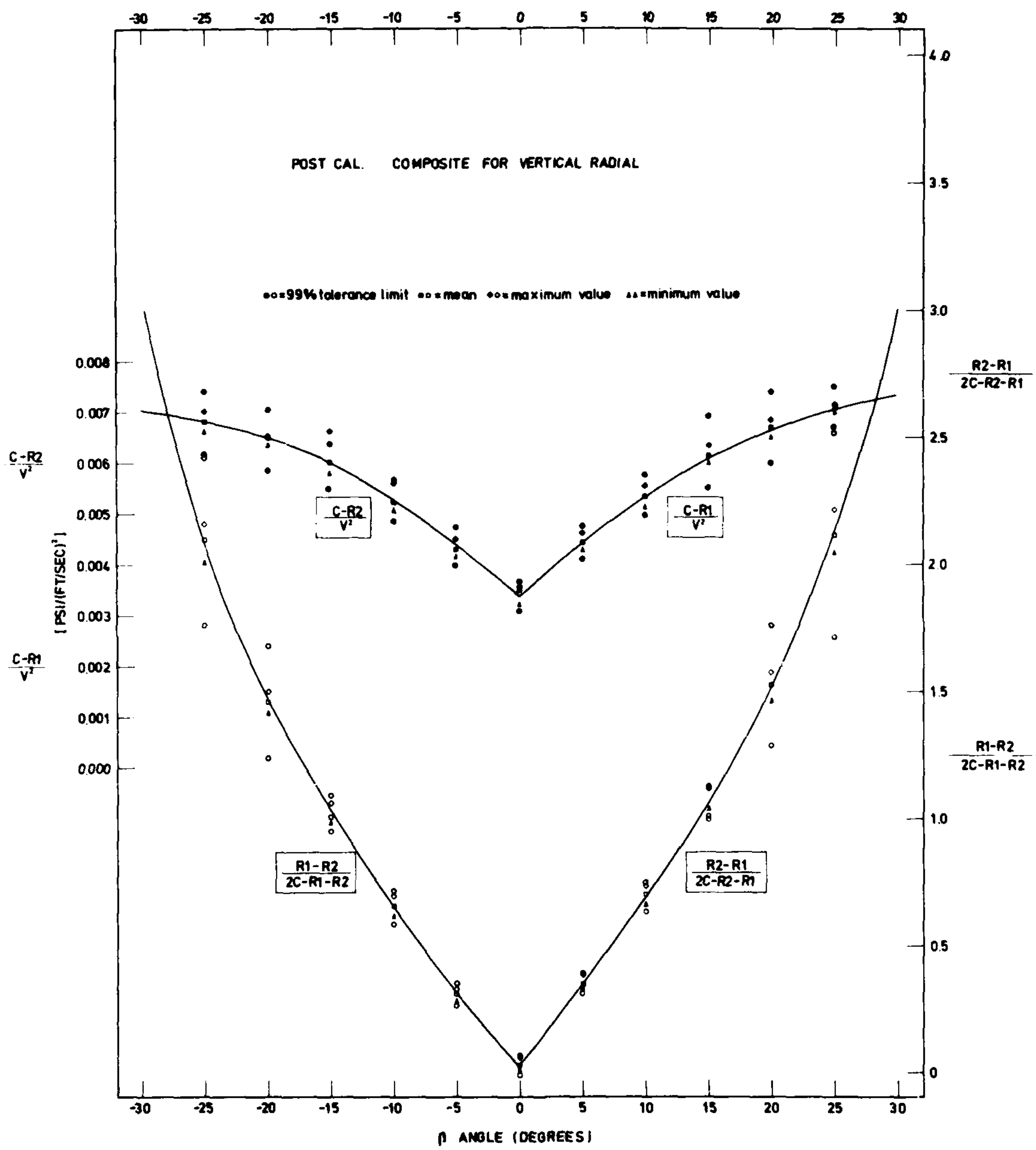


Figure 24 - Composite Plot of 5-Hole Pitot Tube Calibrations in the Vertical-Radial Plane

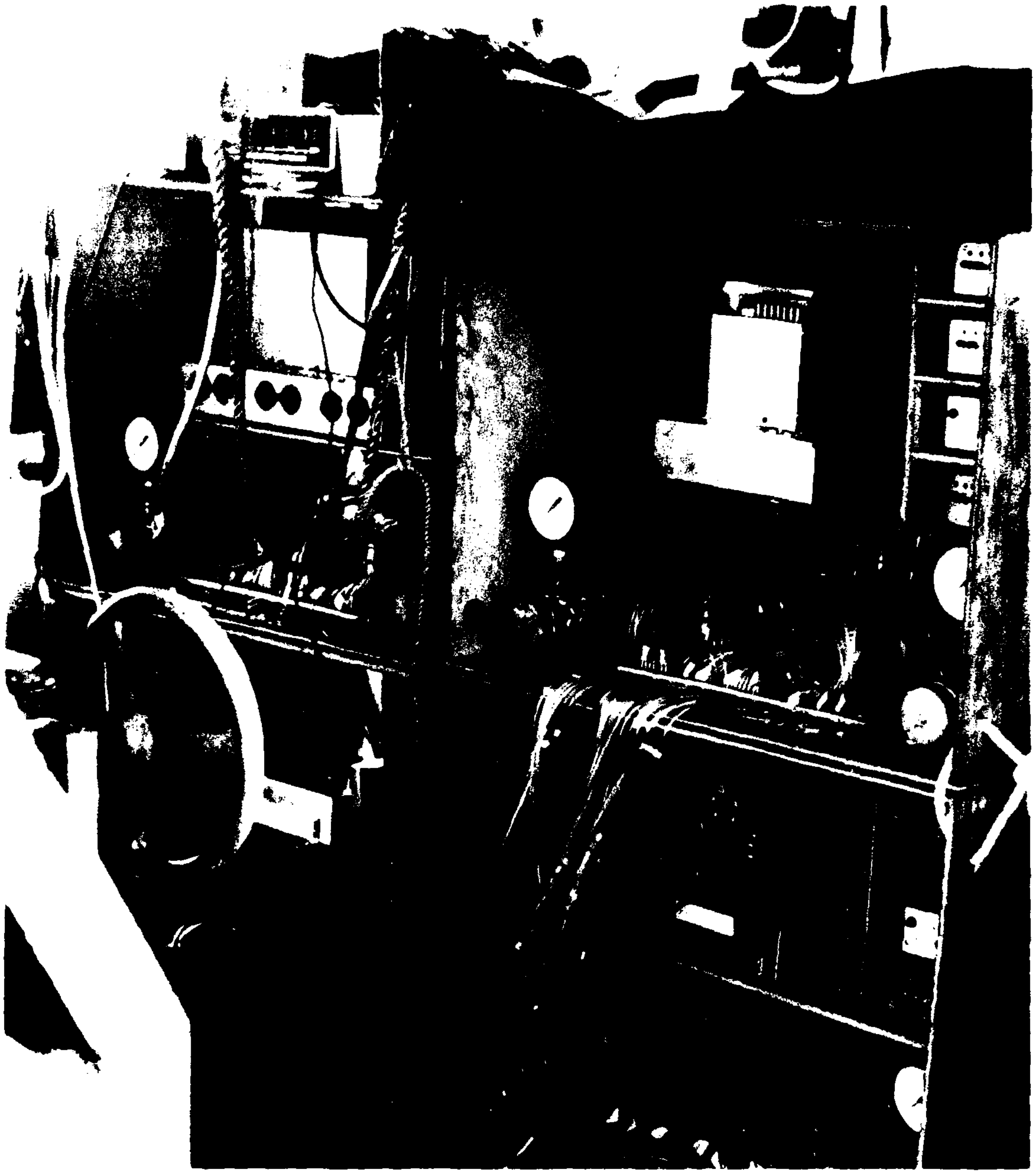


Figure 25 - Assembly of Pressure Tubing, Bleed Manifolds, Scanivalves,
and Electronic Switching Equipment on After Deck of R/V ATHENA

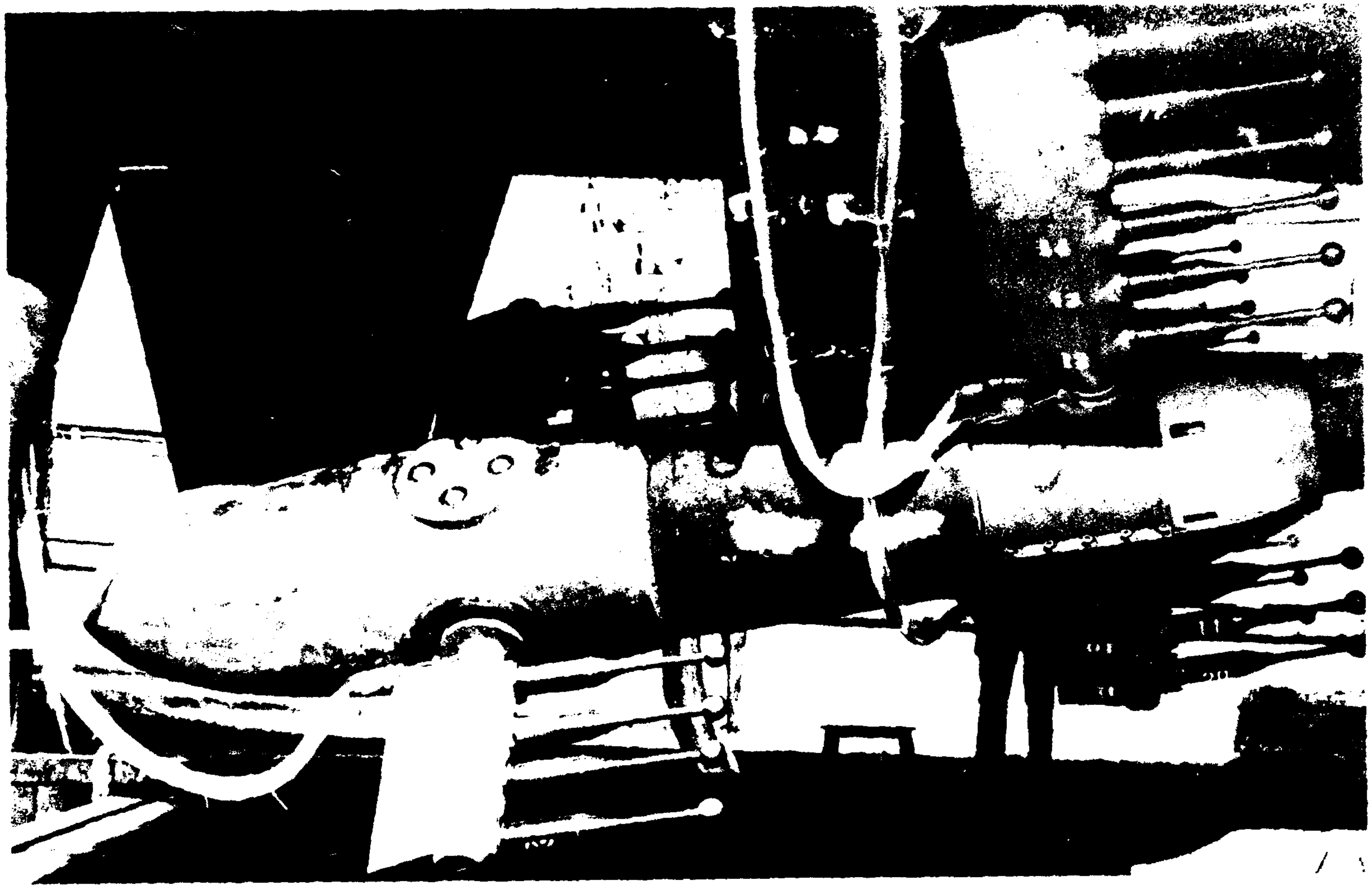


Figure 26 - Starboard Shaft Pitot Tube Rakes A, B, C and E Prior to Installation of Protective Piping

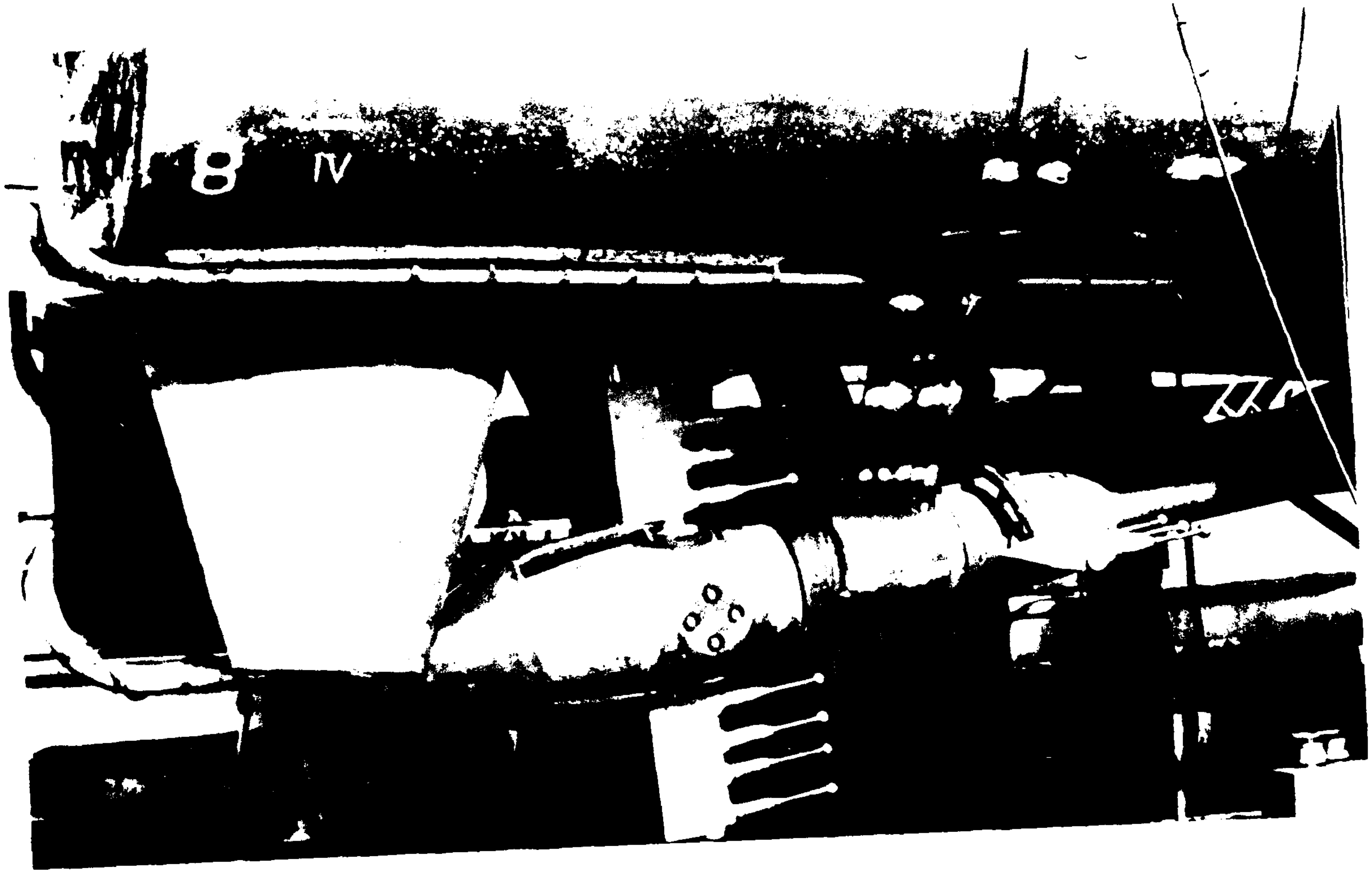


Figure [illegible]7 - Starboard Shaft Pitot Tube Rakes A, B, C and D After Installation of Protective Fairing

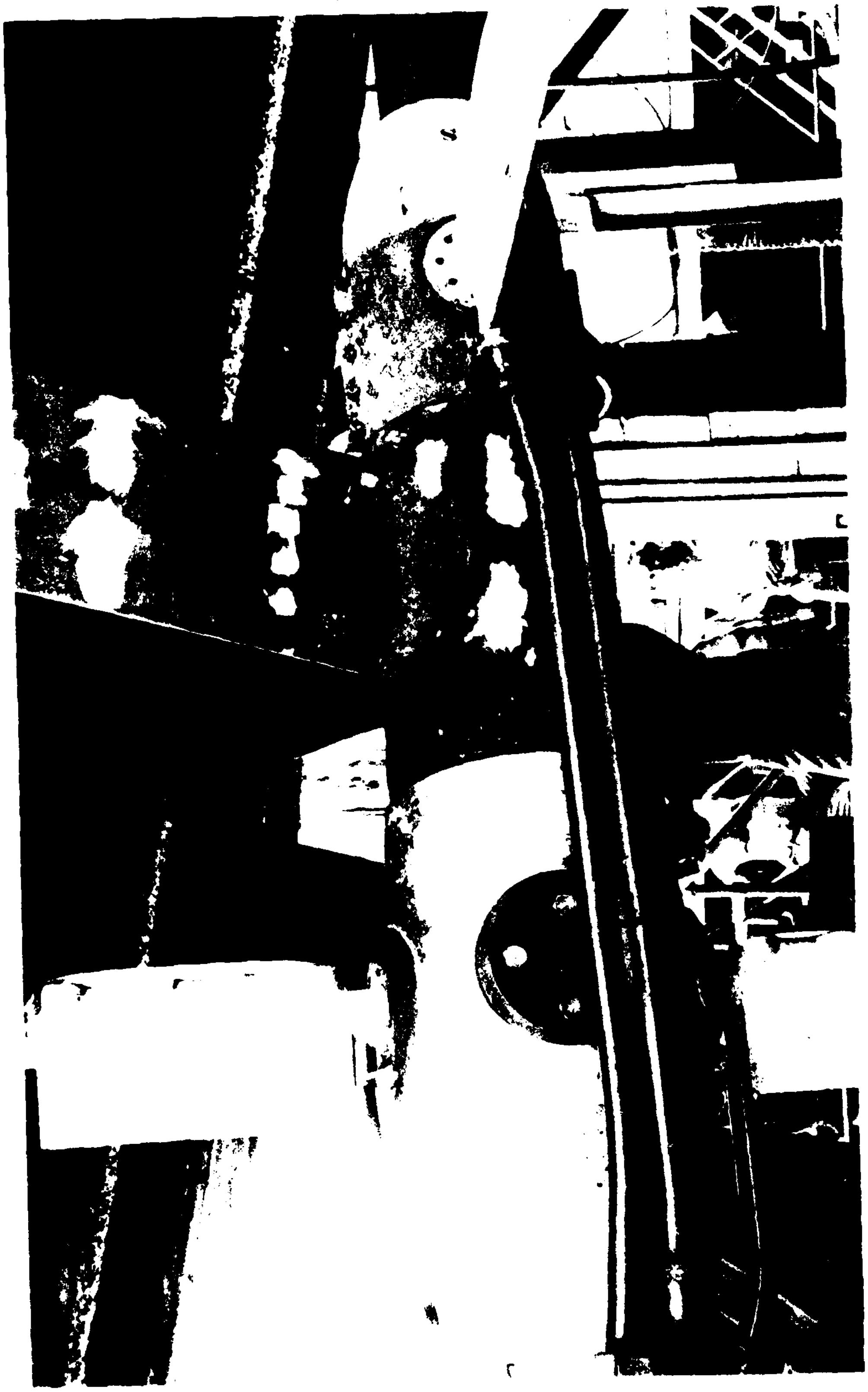


Figure 28 - Piping to Protect Pressure Tubing of Starboard Pitot Tube Rakes

Figure 29 - Aft Pitot Tube Rake B on Starboard Shaft Showing Close-Up Arrangement of 5-Hole Sperical Pitot Tubes

Figure 30 - Hub Shield to Protect Pressure Tubing of Starboard Pitot Tube Rakes

Figure 31 - Propeller and Pitot Tube Rakes [illegible] and [illegible] on Port Shaft

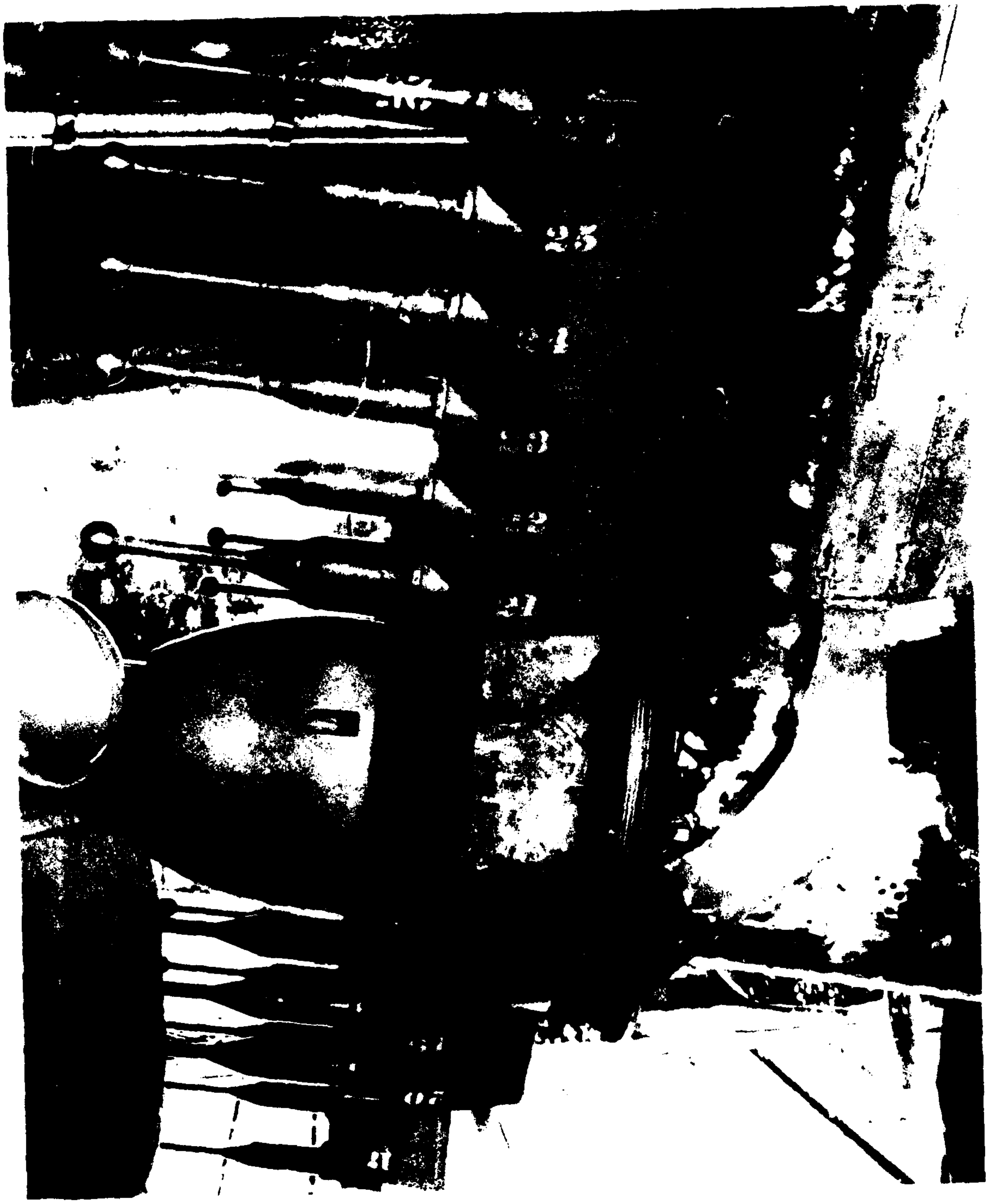


Figure 32 - Close-Up View of Pitot Tube Rakes D and F on Port Shaft

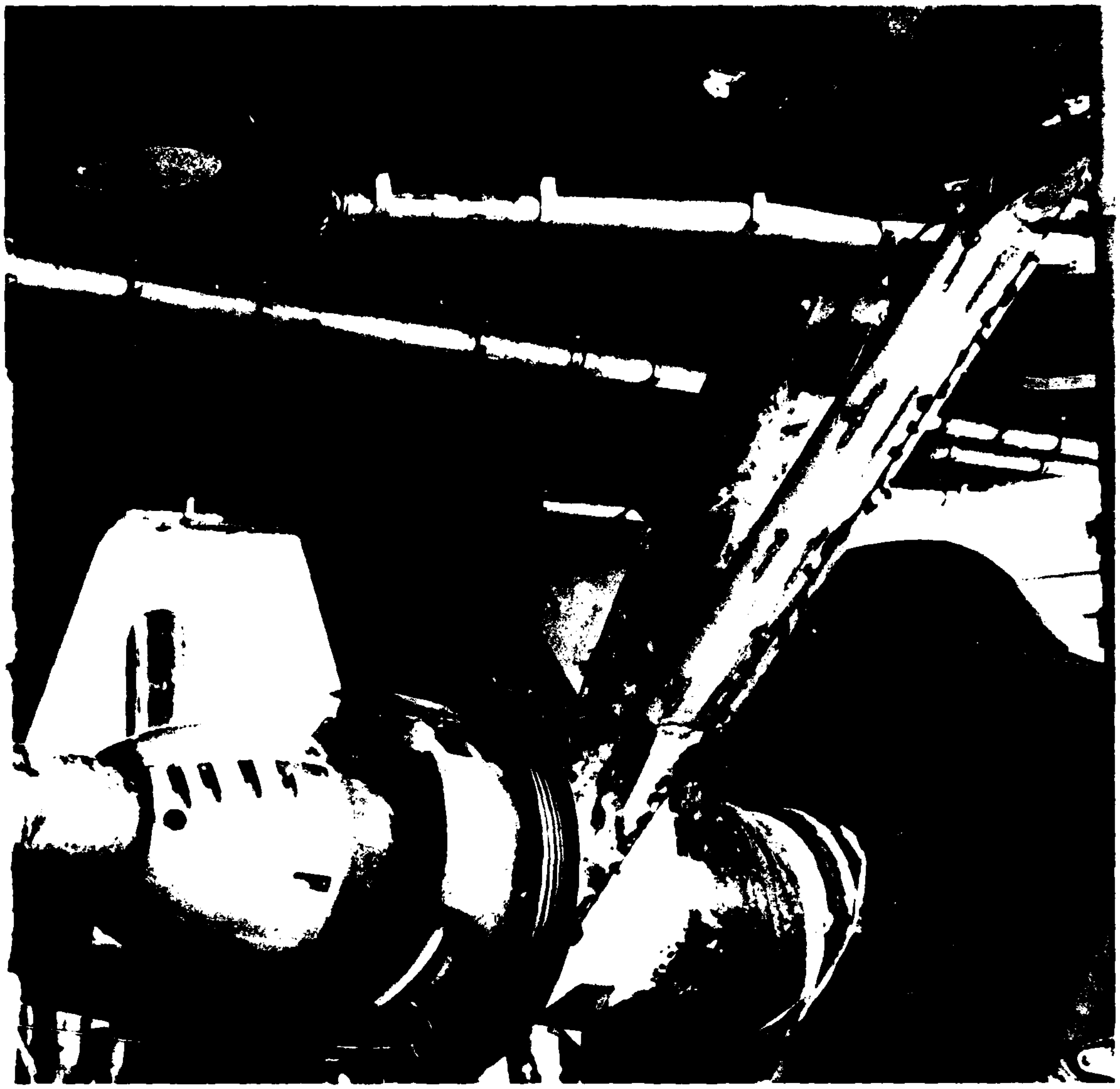


Figure 33 - Port Shaft Pitot Tube Rake Positioning Cable and
Pressure Tubing Protection

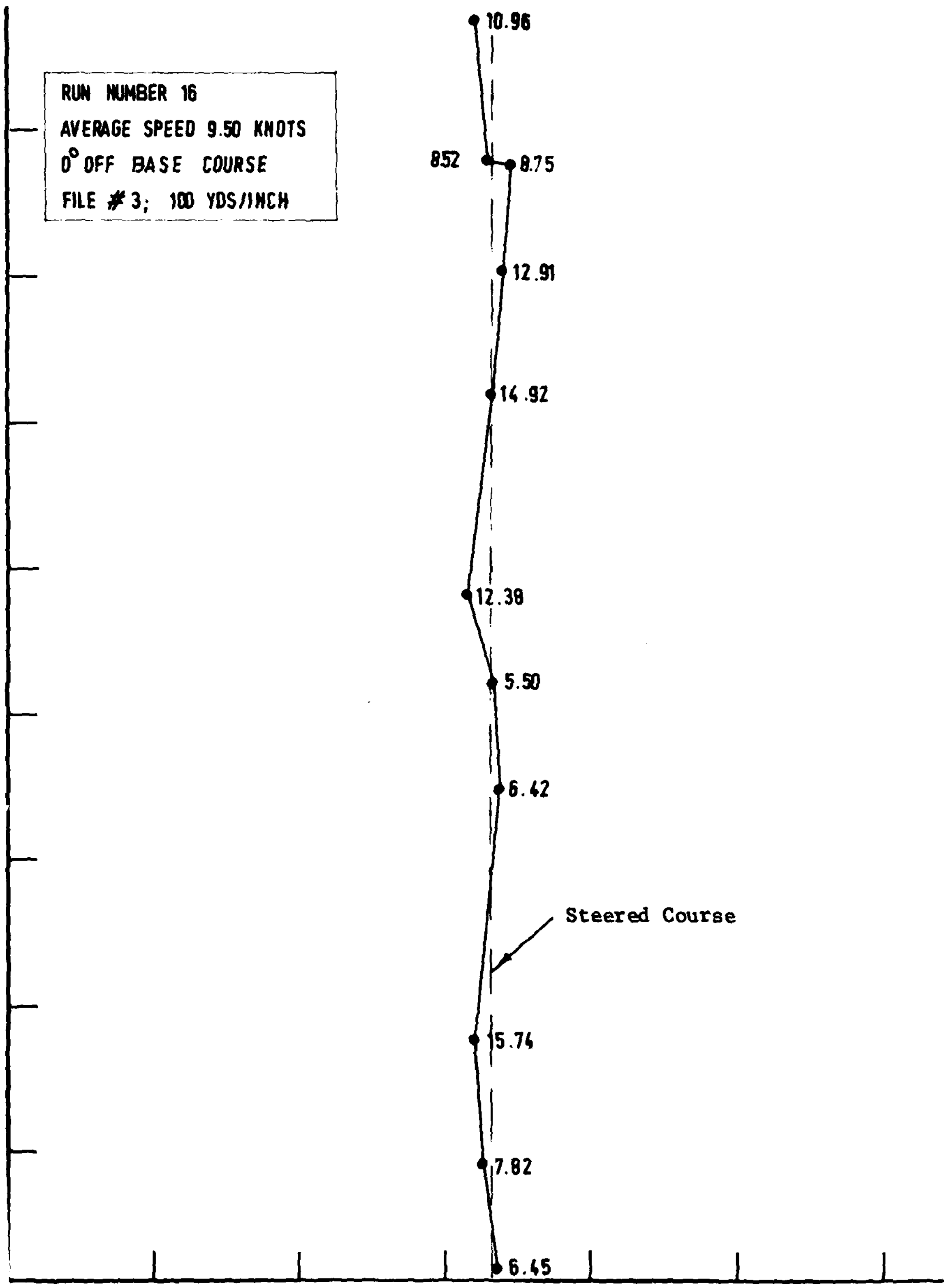


Figure 34 - Ship Course Deviation as Determined by Mini-Ranger (Run 16)

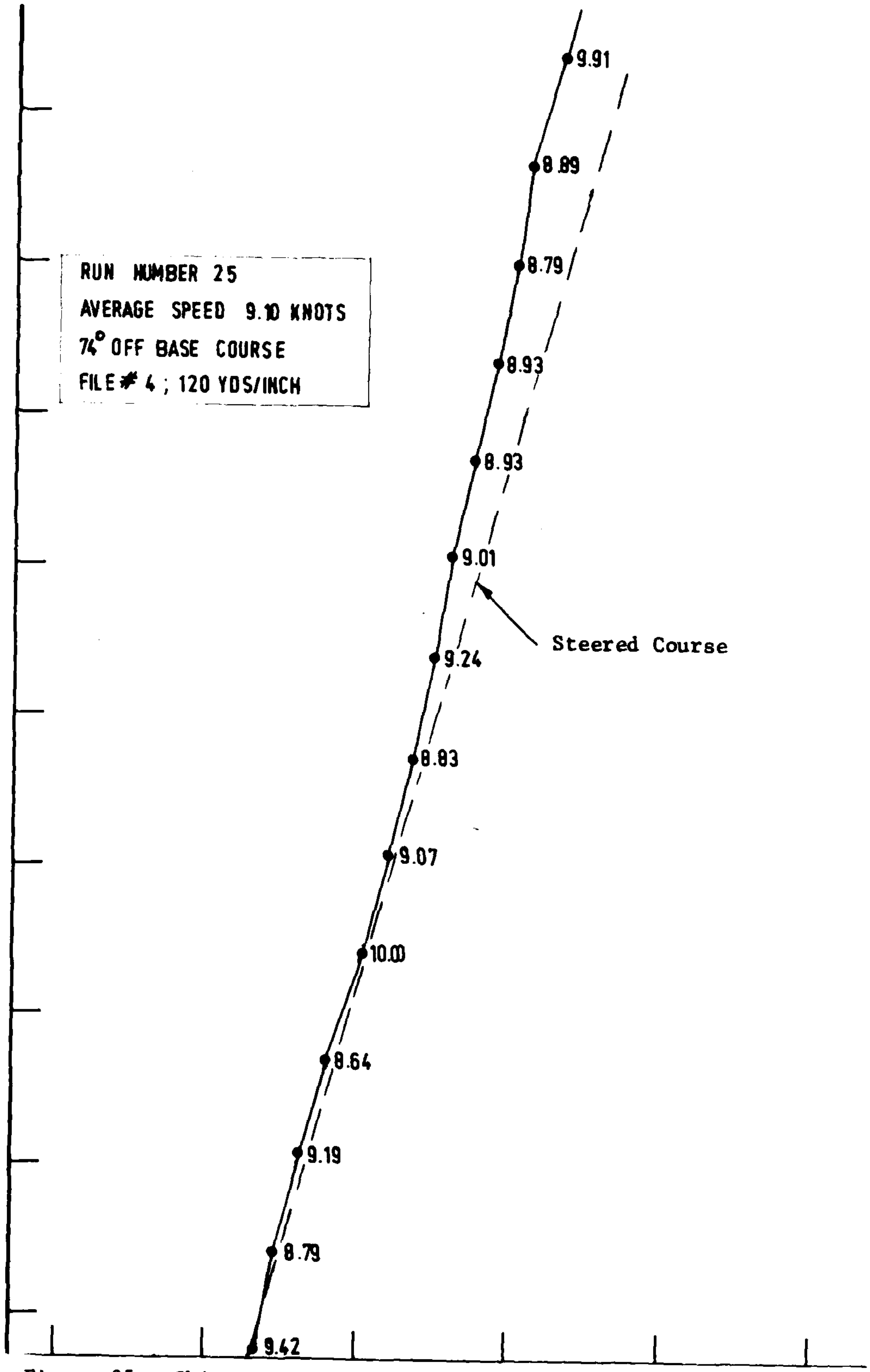
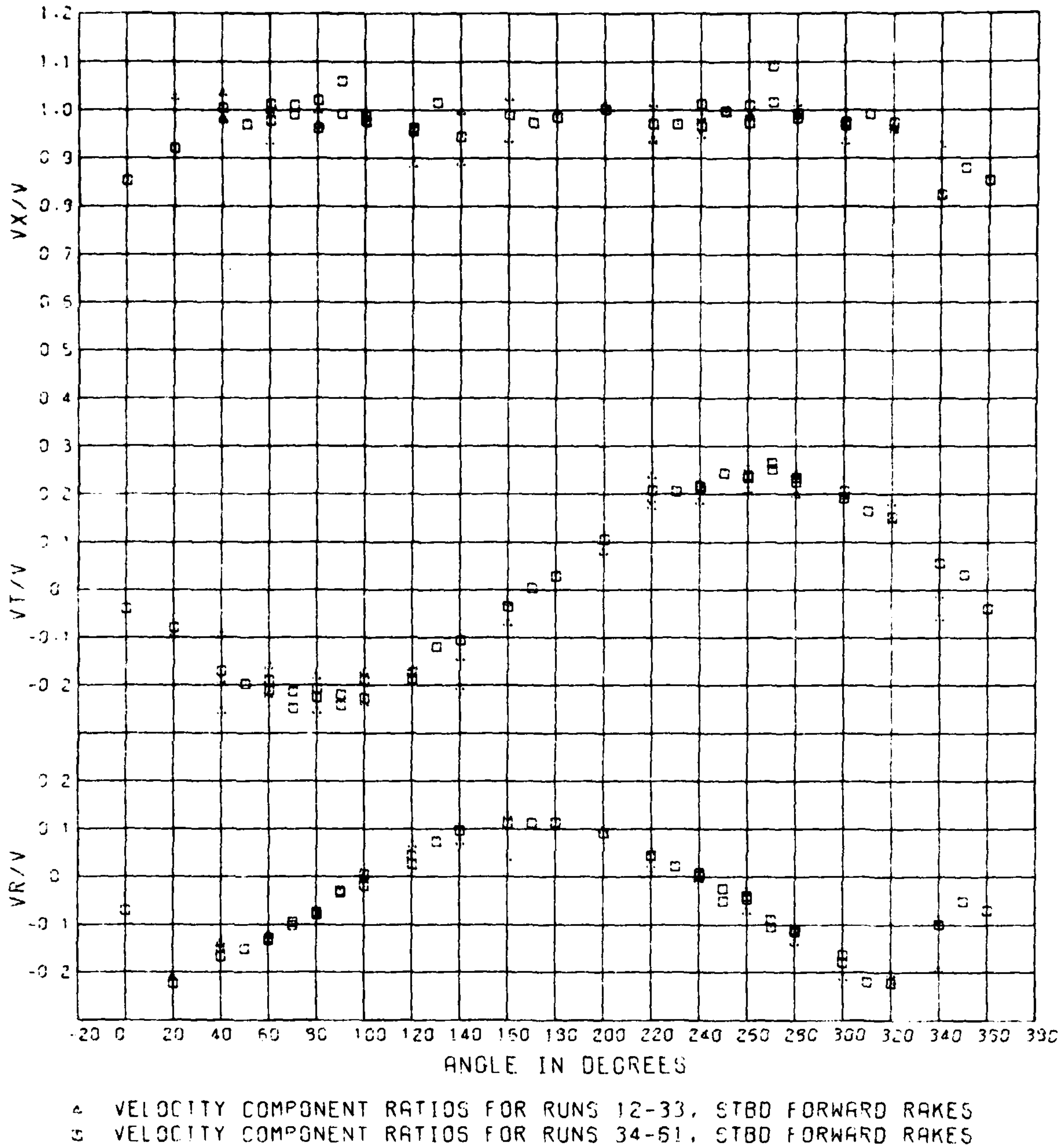


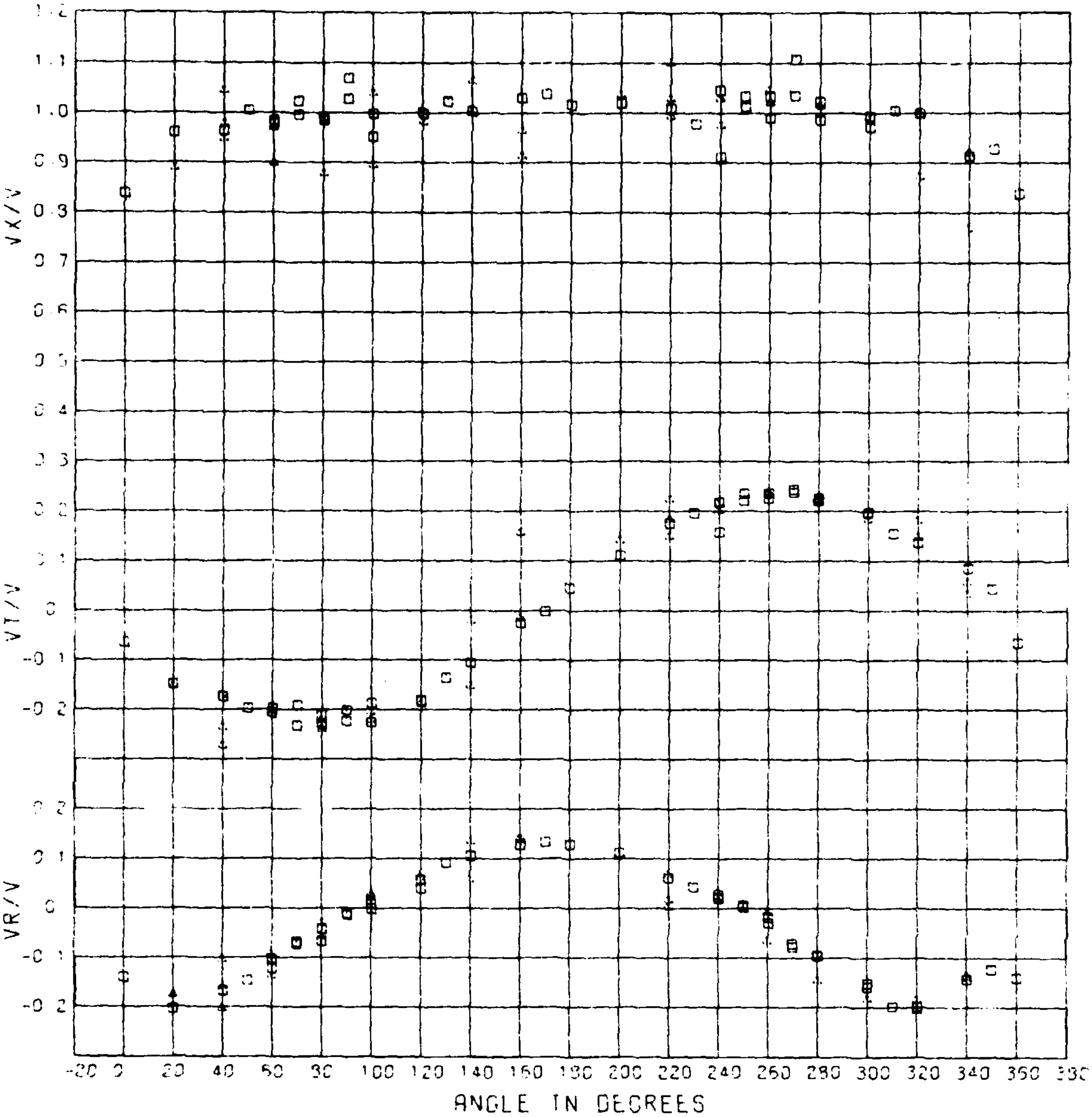
Figure 35 - Ship Course Deviation as Determined by Mini-Ranger (Run 25)



(Forward Plane on Shaft Without Propeller)

0.417 RAD.

Figure 36 - Velocity Component Ratios at 0.417 Radius for Speeds of 8.95 Knots and 15.1 Knots

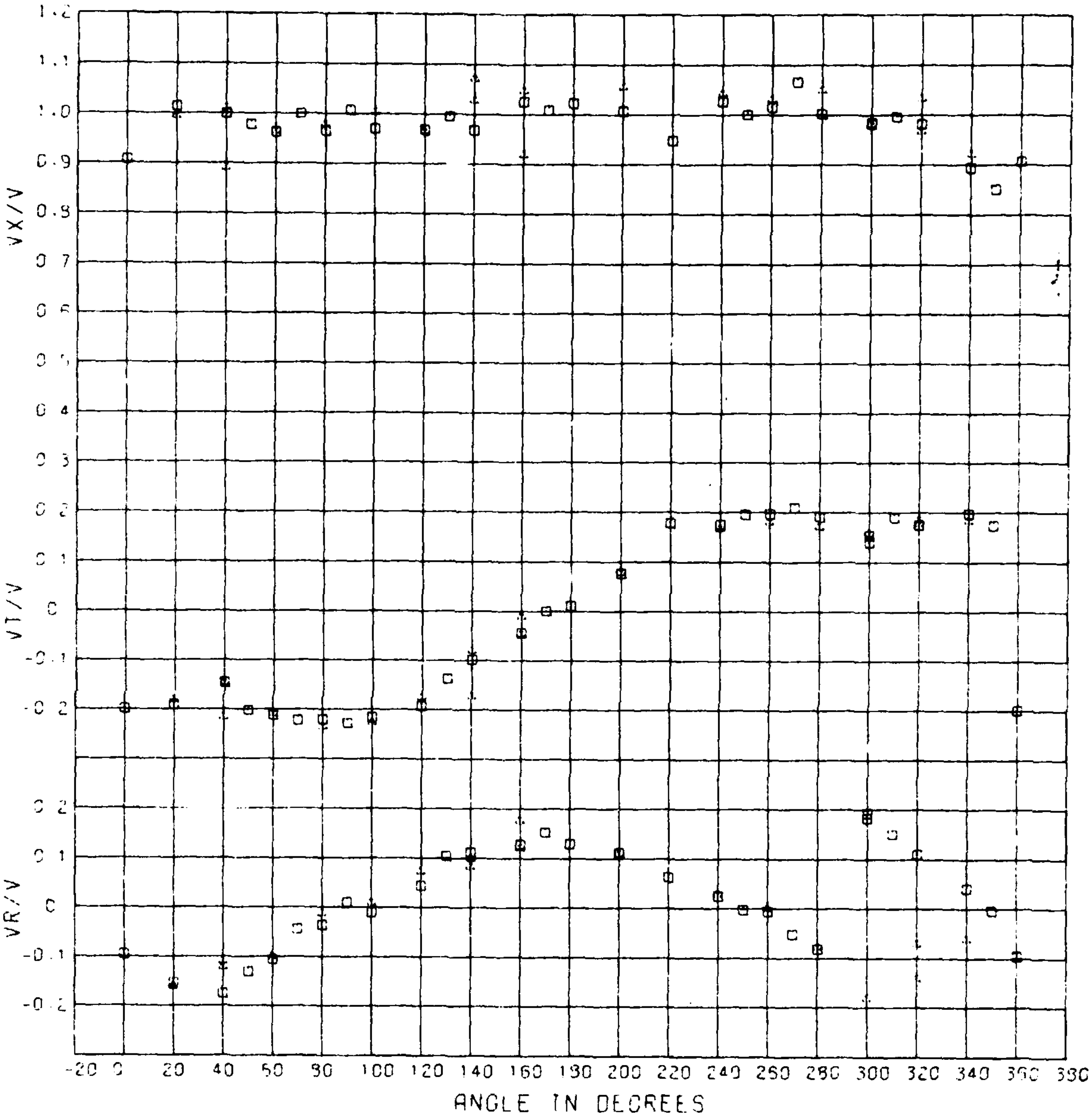


△ VELOCITY COMPONENT RATIOS FOR RUNS 12-33, STBD FORWARD RAKES
□ VELOCITY COMPONENT RATIOS FOR RUNS 34-61, STBD FORWARD RAKES

(Forward Plane on Shaft Without Propeller)

0.583 RAD.

Figure 37 - Velocity Component Ratios at 0.583 Radius for Speeds of 8.95 Knots and 15.1 Knots



△ VELOCITY COMPONENT RATIOS FOR RUNS 12-33, STBD FORWARD RAKES
□ VELOCITY COMPONENT RATIOS FOR RUNS 34-61, STBD FORWARD RAKES

(Forward Plane on Shaft Without Propeller)

0.750 RAD.

Figure 38 - Velocity Component Ratios at 0.750 Radius for Speeds of 8.95 Knots and 15.1 Knots

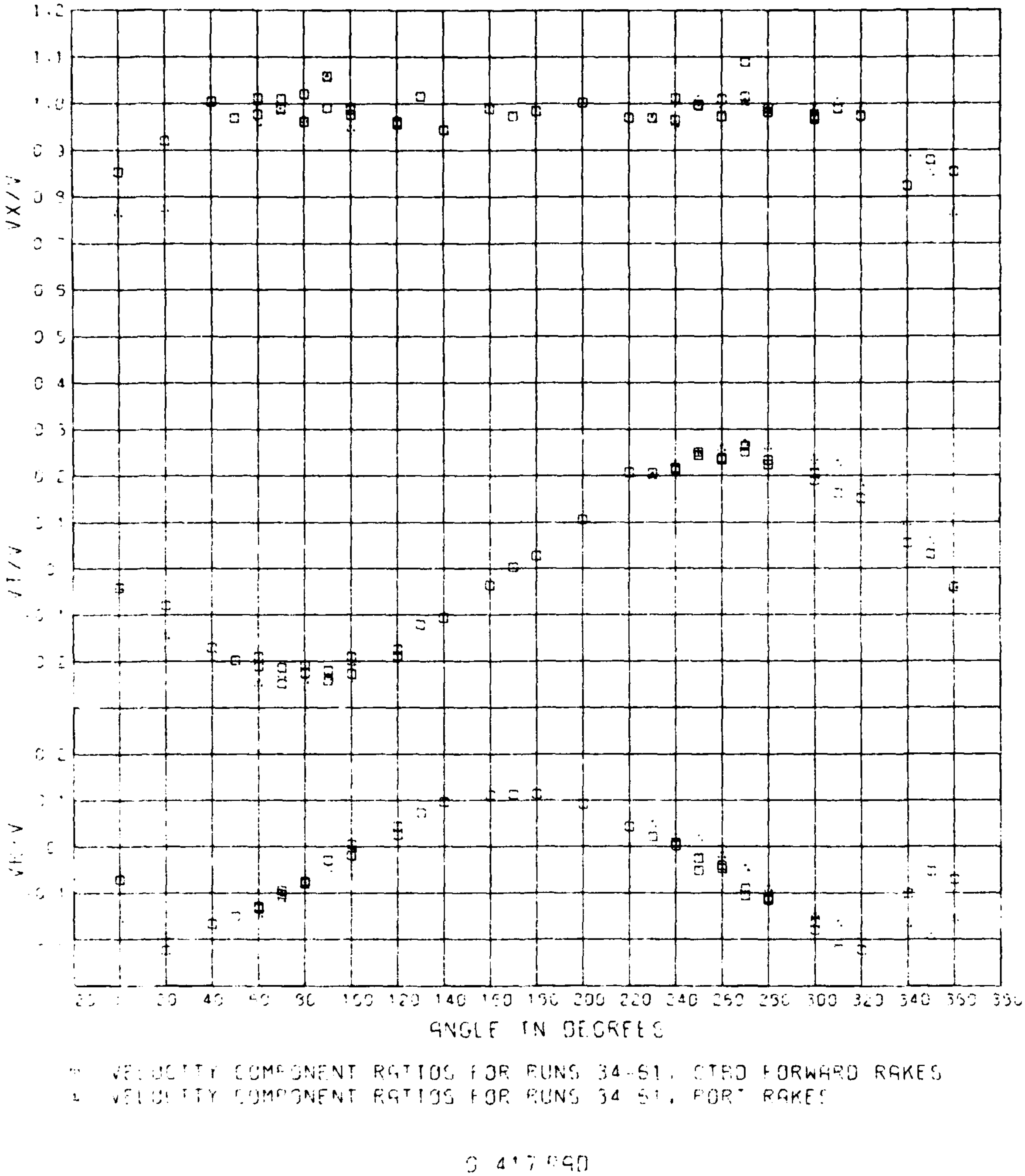


Figure 39 - Velocity Component Ratios for Runs 34-61, Port and Starboard Forward Rakes, at a r/R of 0.417

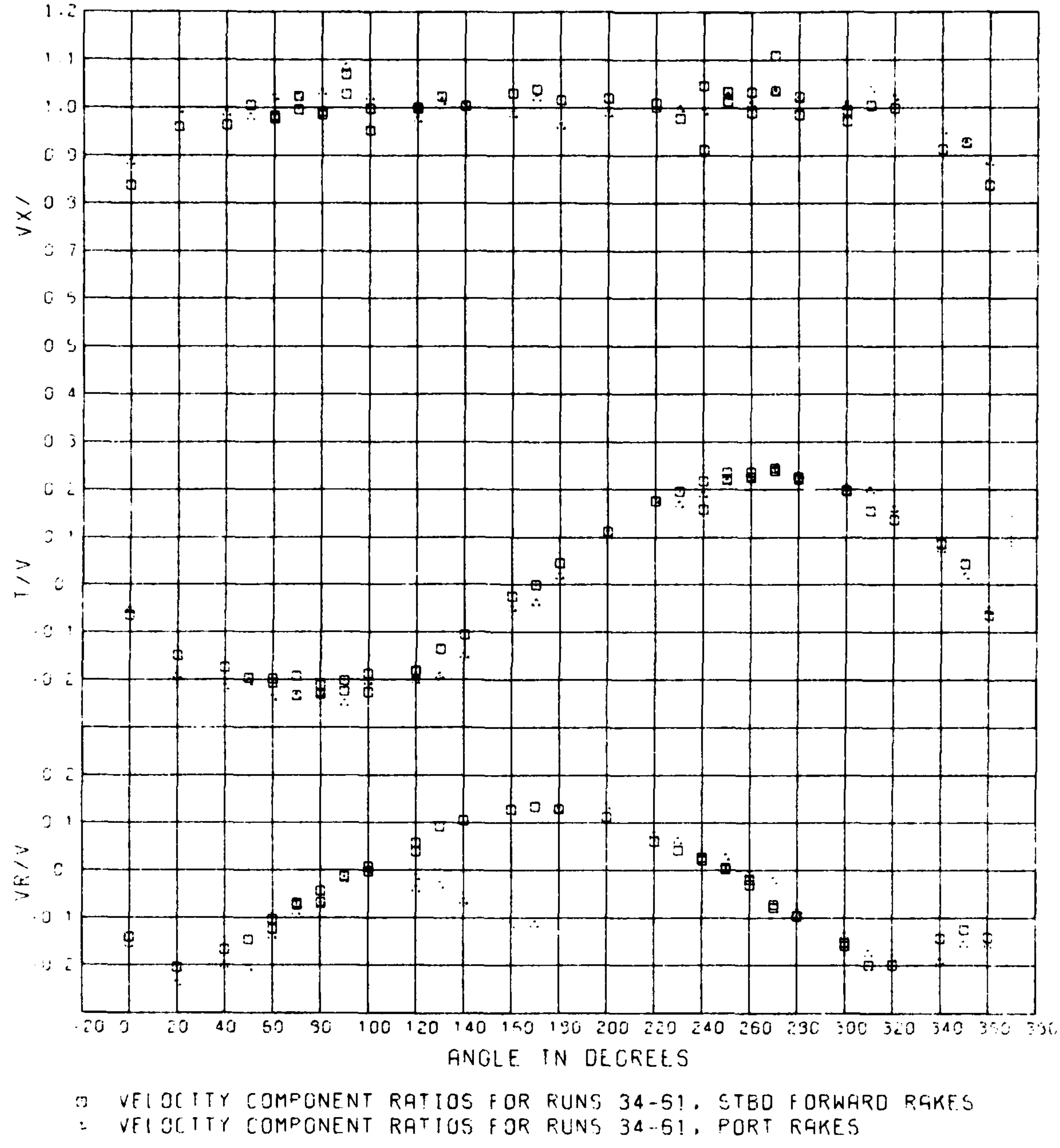


Figure 40 - Velocity Component Ratios for Runs 34-61, Port and Starboard Forward Rakes, at a r/R of 0.583

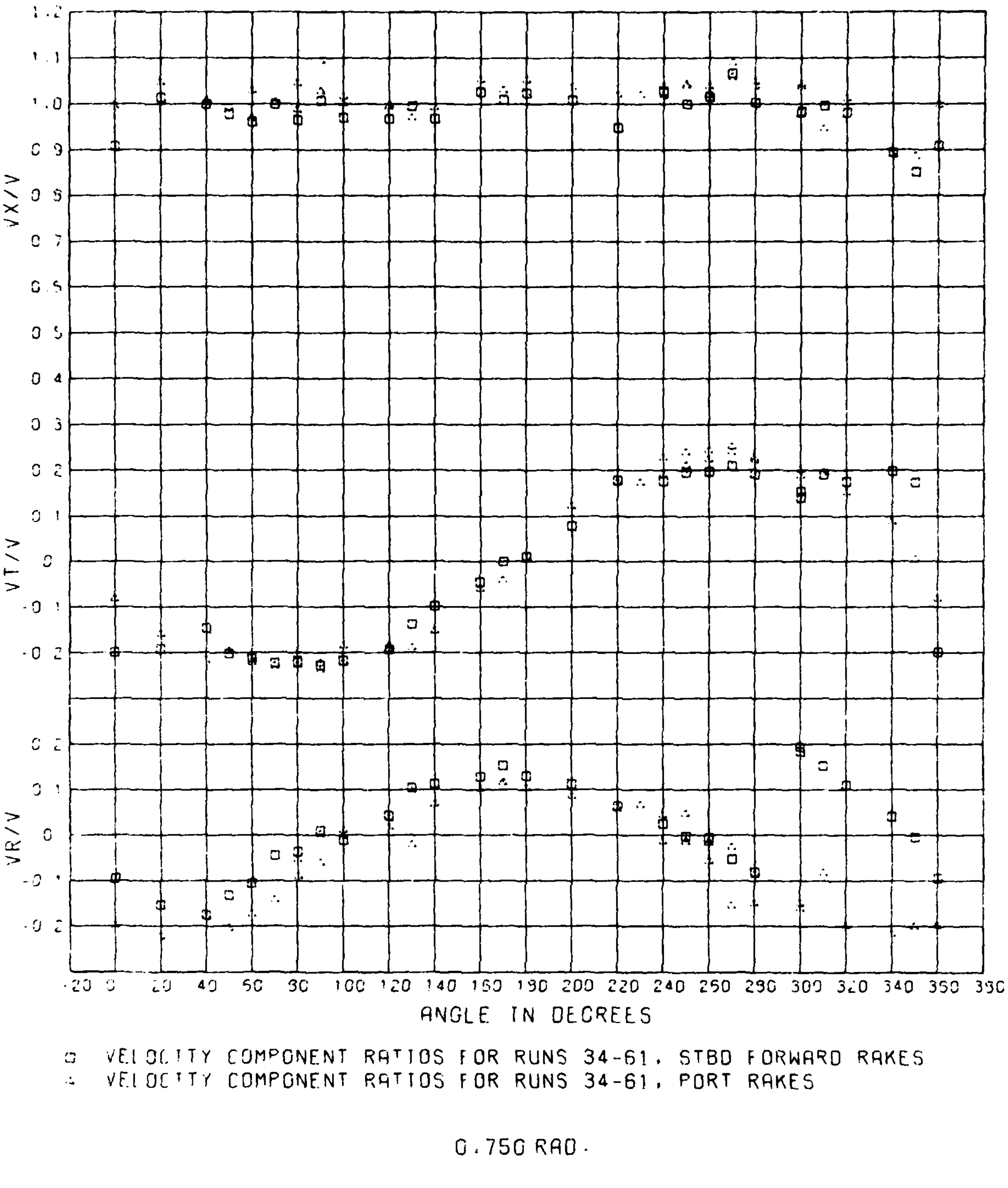


Figure 41 - Velocity Component Ratios for Runs 34-61, Port and Starboard Forward Rakes, at a r/R of 0.750

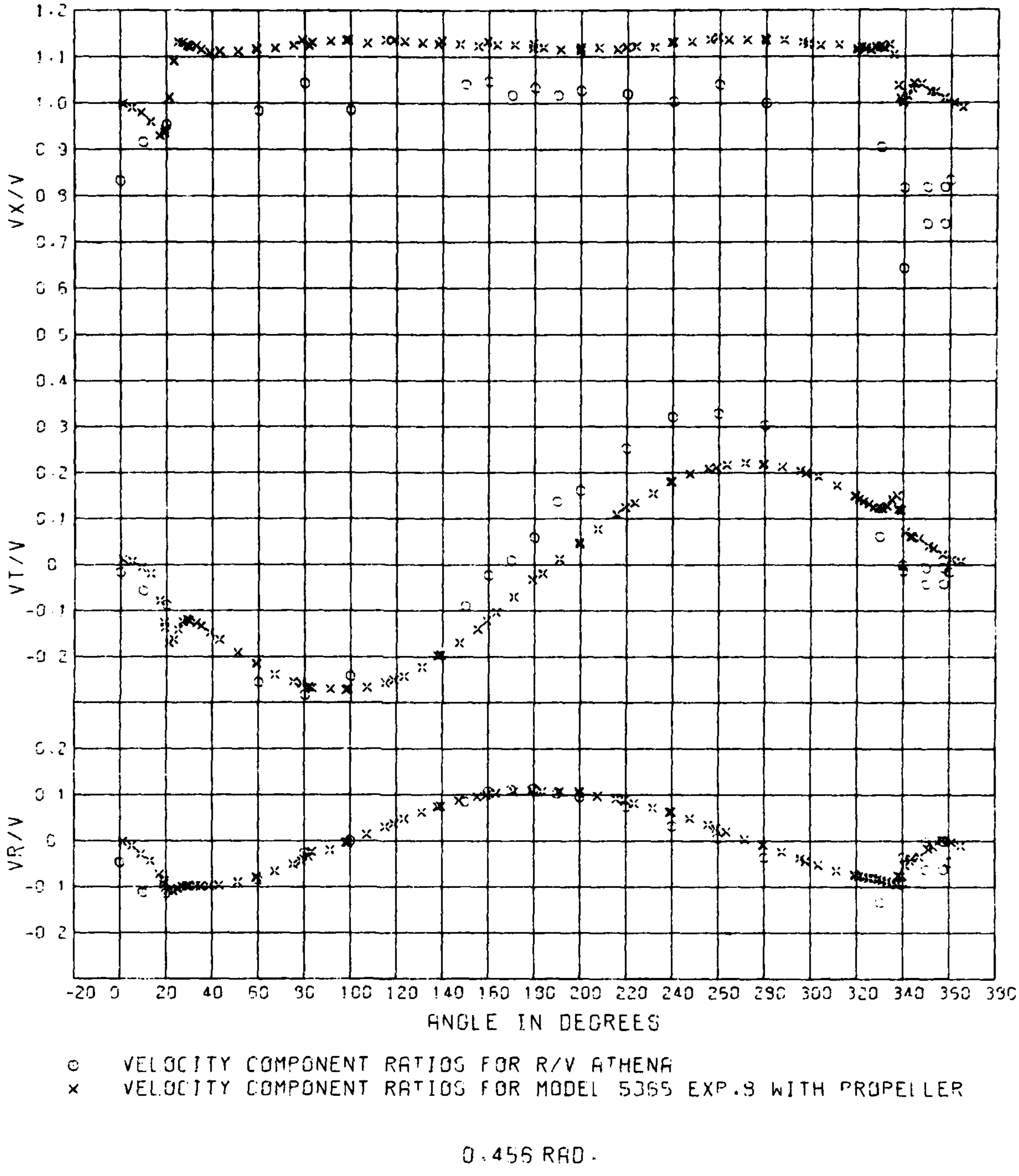
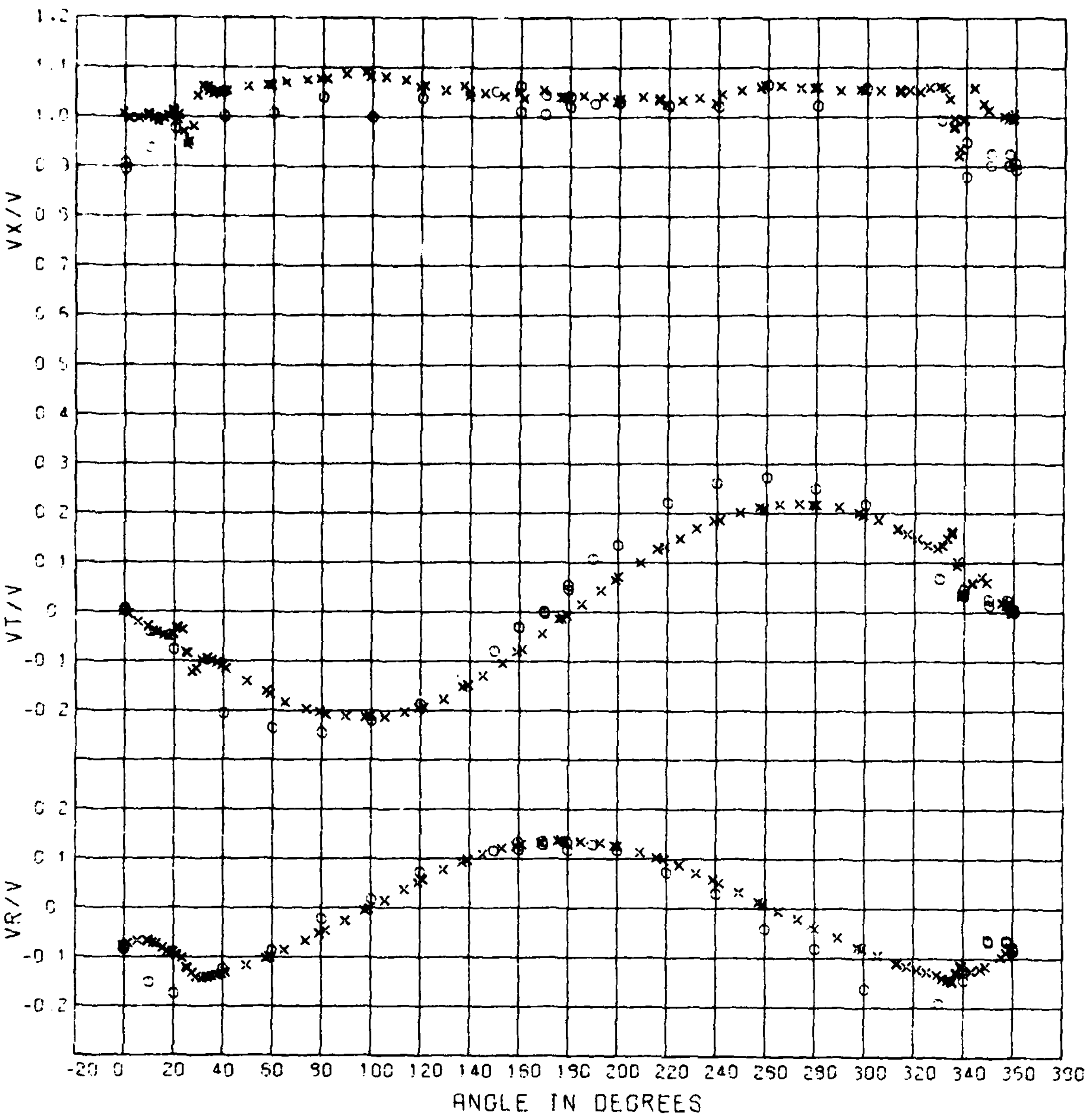


Figure 42 - Composite Plot of Velocity Component Ratios for R/V ATHENA and Model Experiment 8 at a r/R of 0.456



○ VELOCITY COMPONENT RATIOS FOR R/V ATHENA
× VELOCITY COMPONENT RATIOS FOR MODEL 5365 EXP.8 WITH PROPELLER

0.633 RAD.

Figure 43 - Composite Plot of Velocity Component Ratios for R/V ATHENA and Model Experiment 8 at a r/R of 0.633

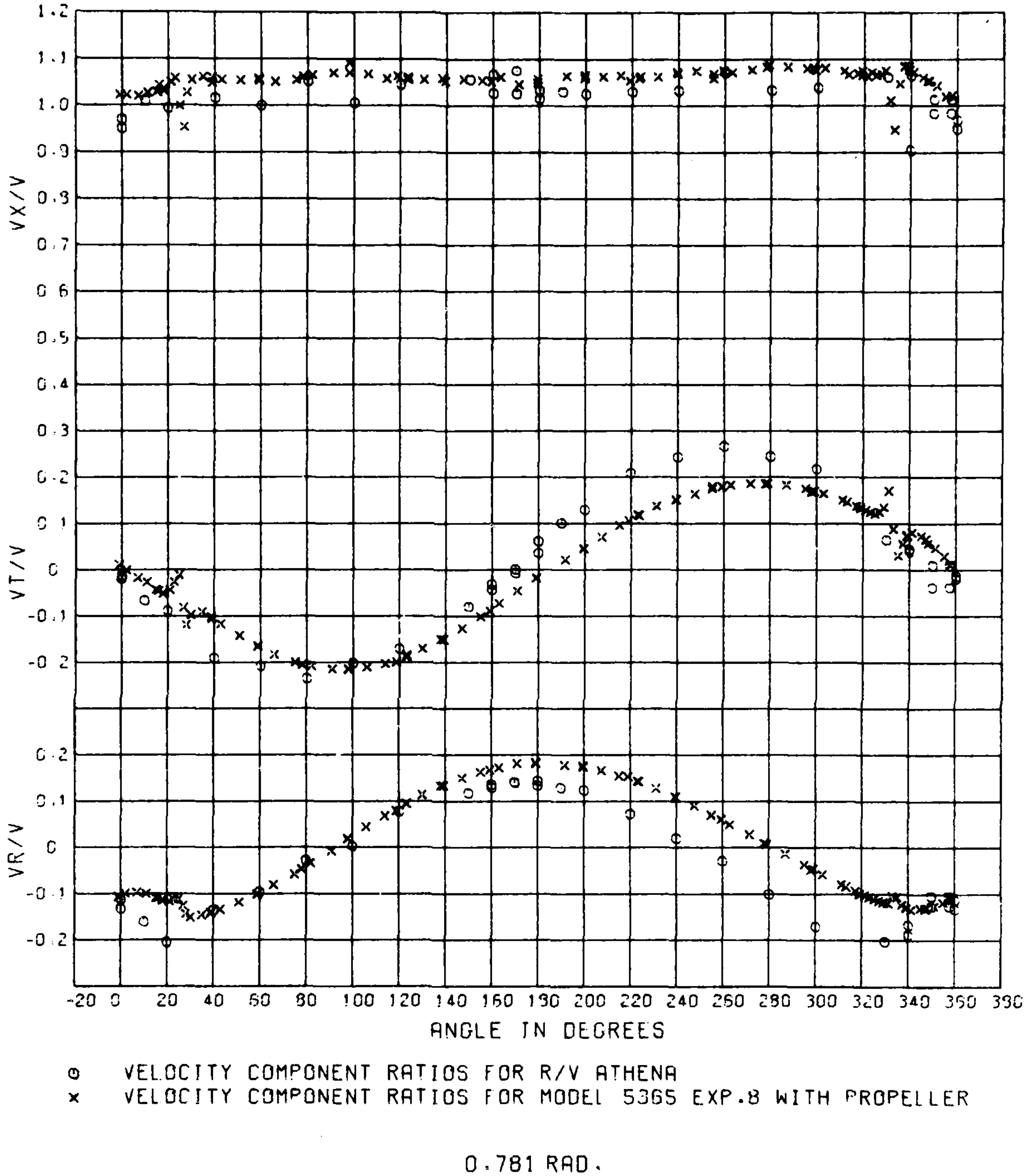


Figure 44 - Composite Plot of Velocity Component Ratios for R/V ATHENA and Model Experiment 8 at a r/R of 0.781

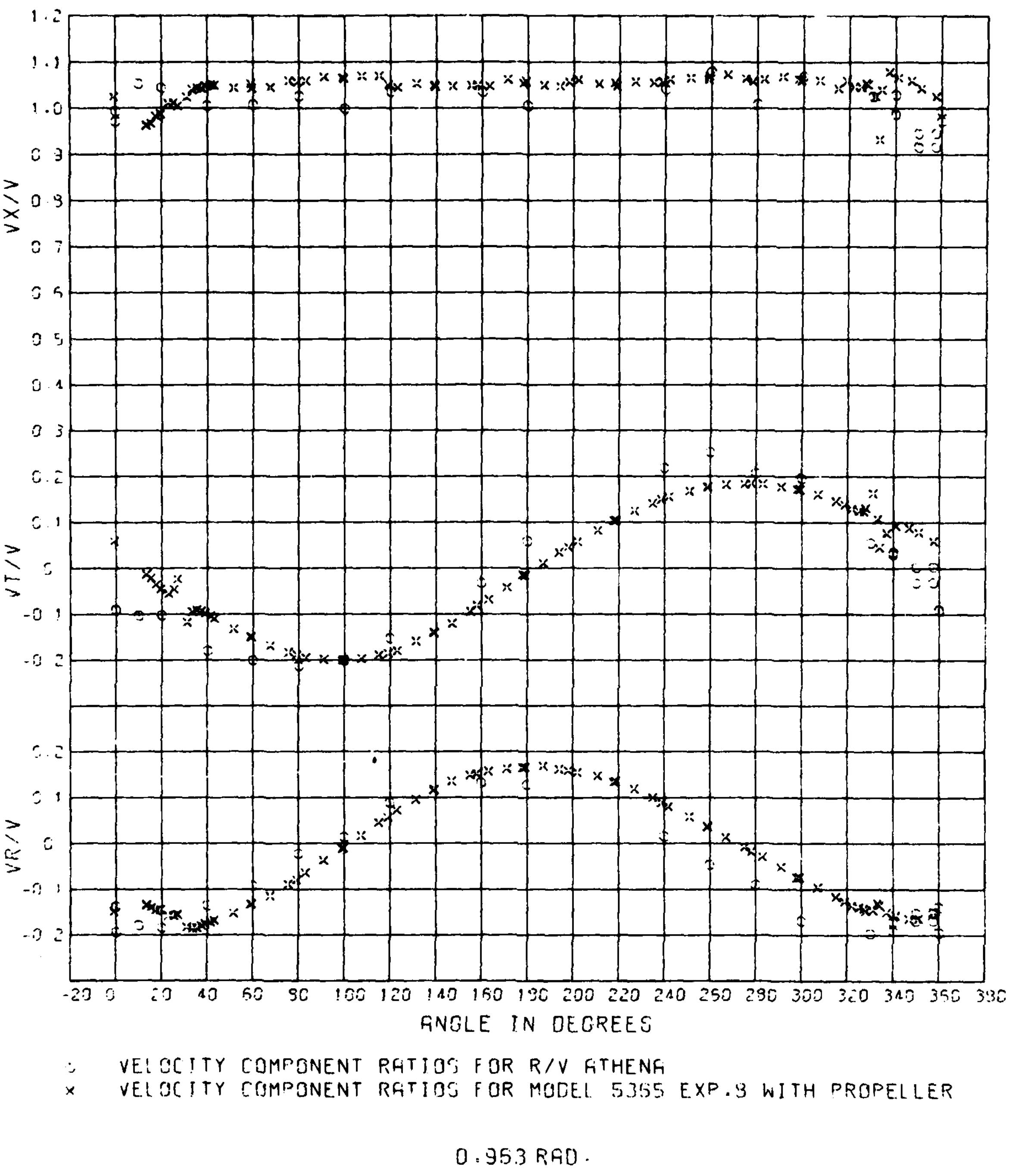


Figure 45 - Composite Plot of Velocity Component Ratios for R/V ATHENA and Model Experiment 8 at a r/R of 0.963

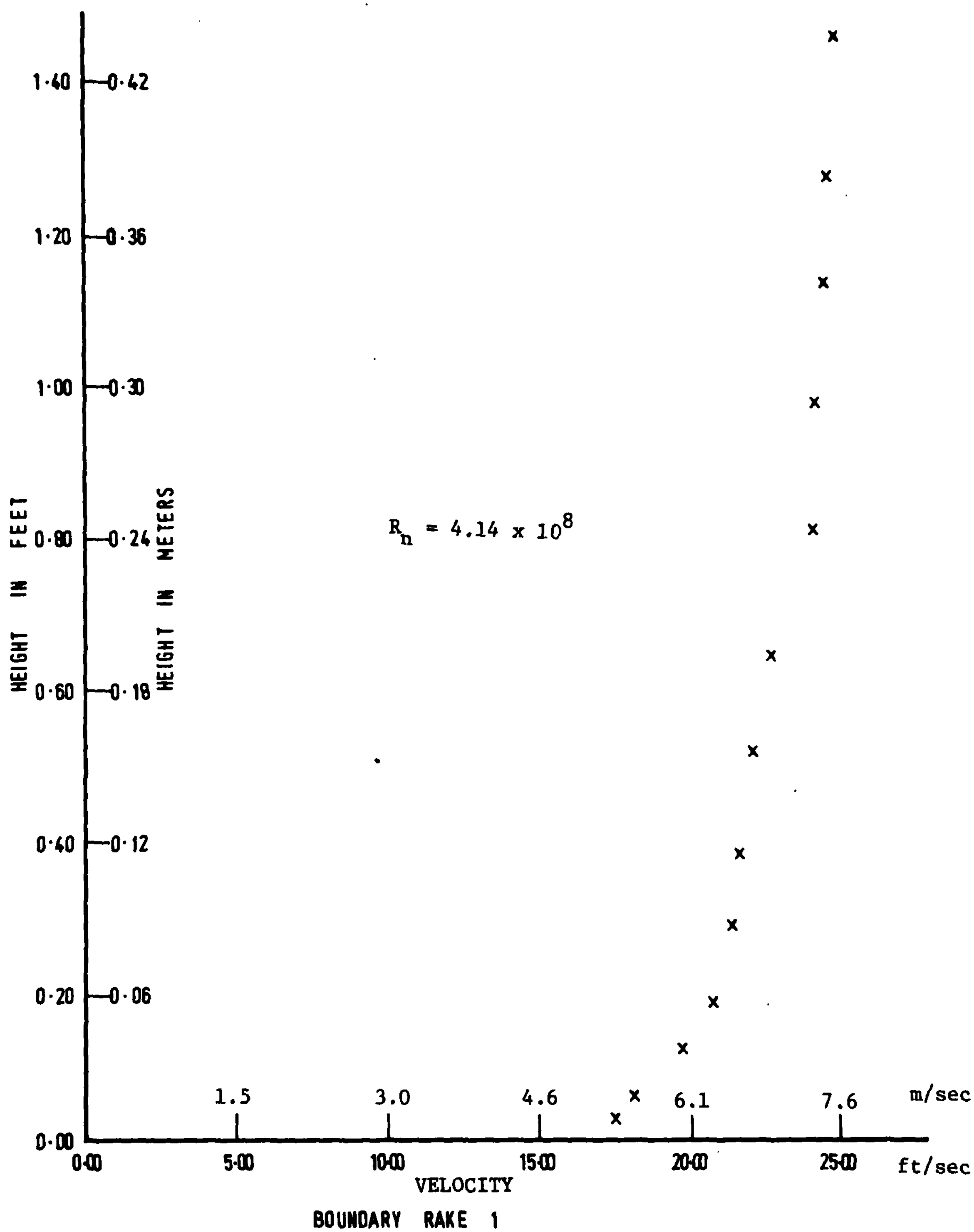


Figure 46 - Boundary Layer Velocity Profile Measured on Rake 1 at a Speed of 24.98 Ft/Sec (7.61 m/sec)

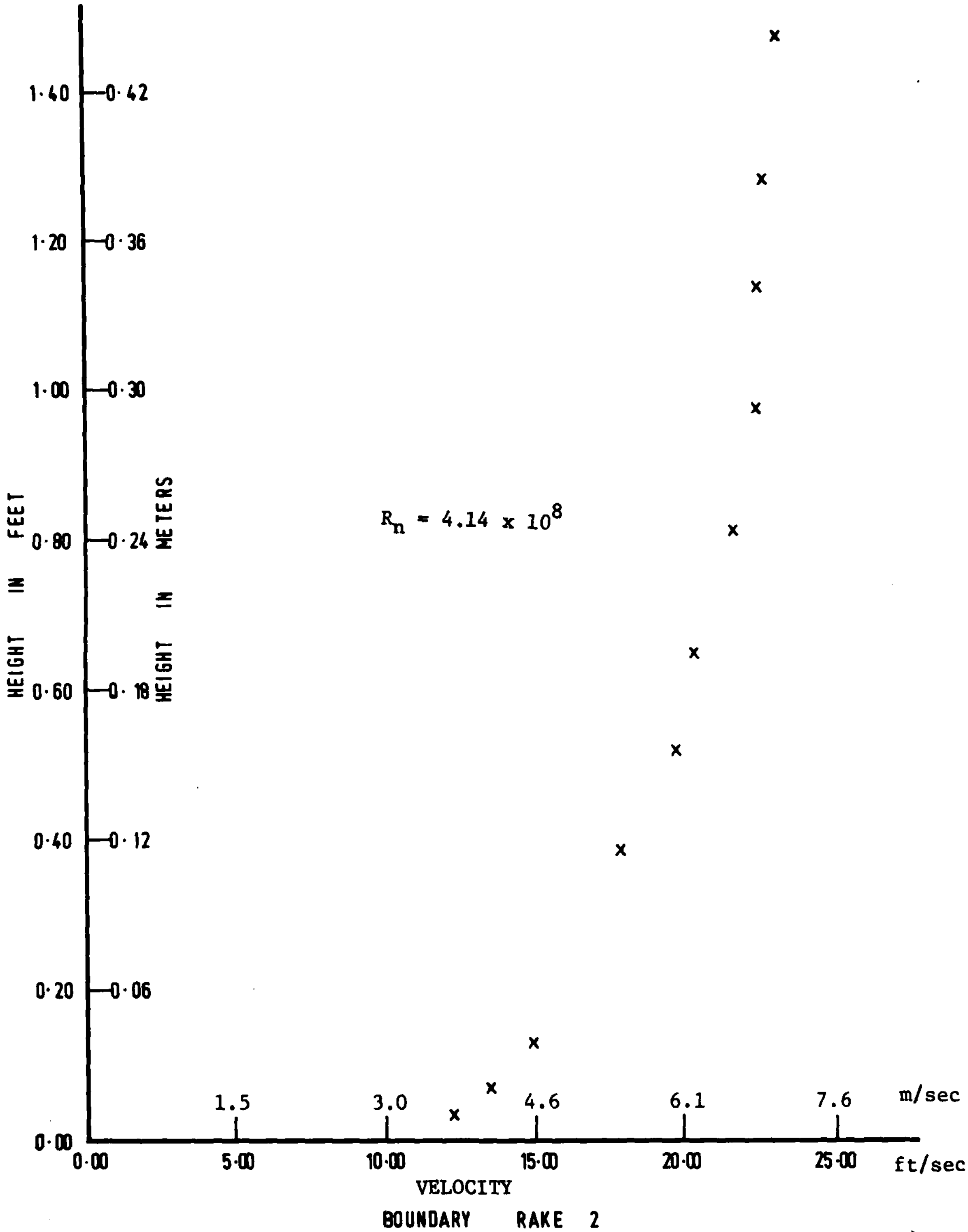


Figure 47 - Boundary Layer Velocity Profile Measured on Rake 2 at a Speed of 24.98 Ft/Sec (7.61 m/sec)

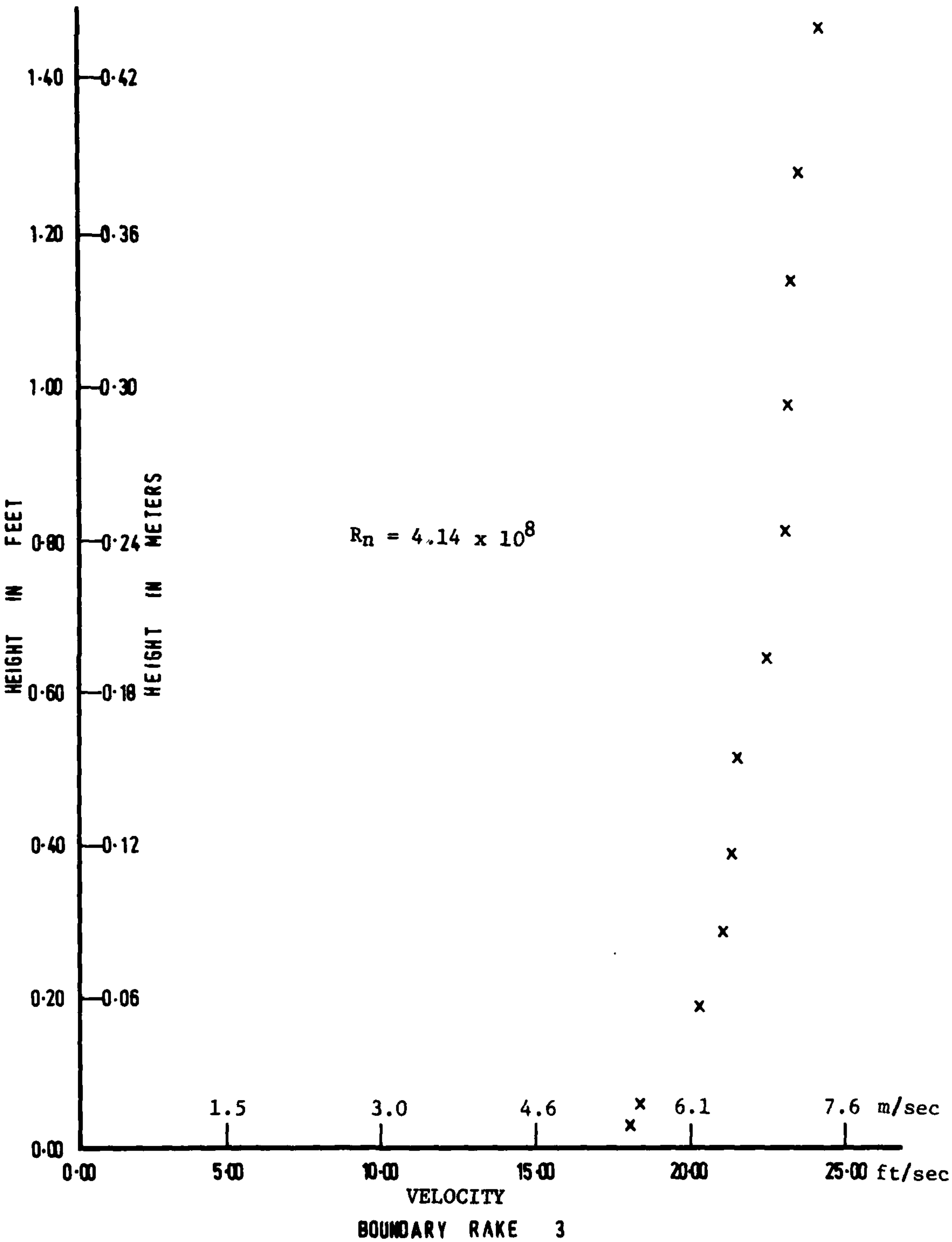


Figure 48 - Boundary Layer Velocity Profile Measured on Rake 3 at a Speed of 24.98 Ft/Sec (7.61 m/sec)

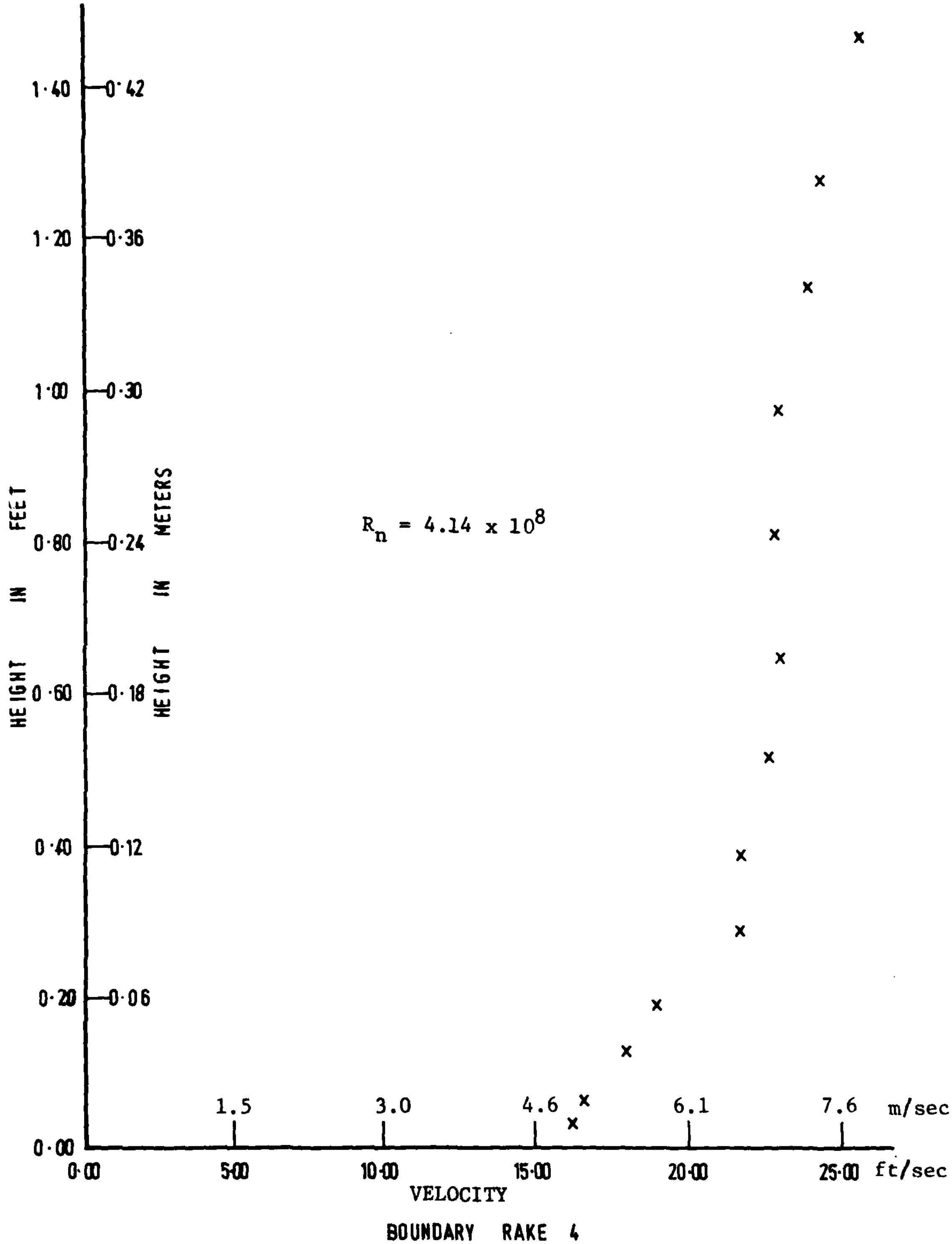


Figure 49 - Boundary Layer Velocity Profile Measured on Rake 4 at a Speed of 24.98 Ft/Sec (7.61 m/sec)

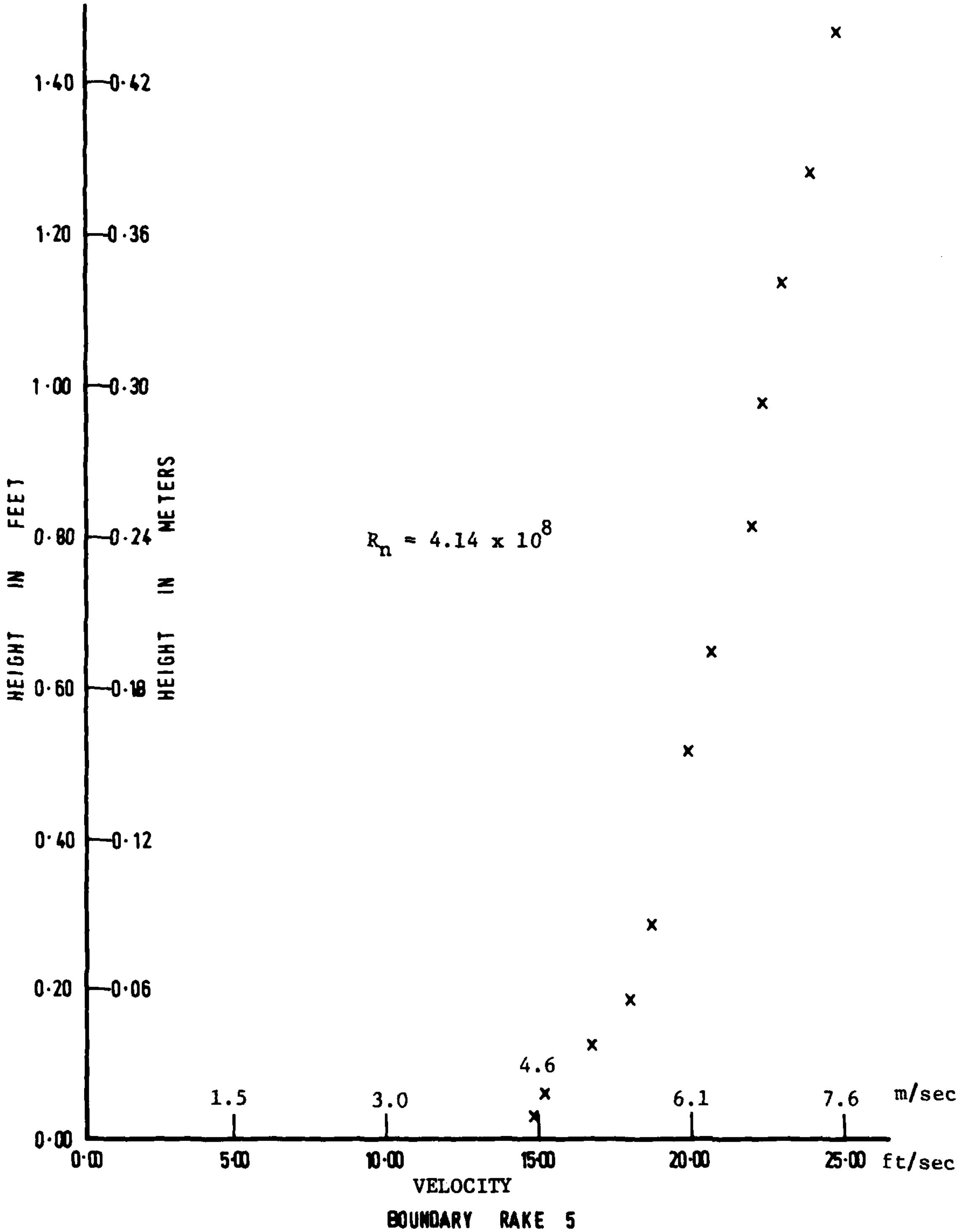


Figure 50 - Boundary Layer Velocity Profile Measured on Rake 5 at a Speed of 24.98 Ft/Sec (7.61 m/sec)

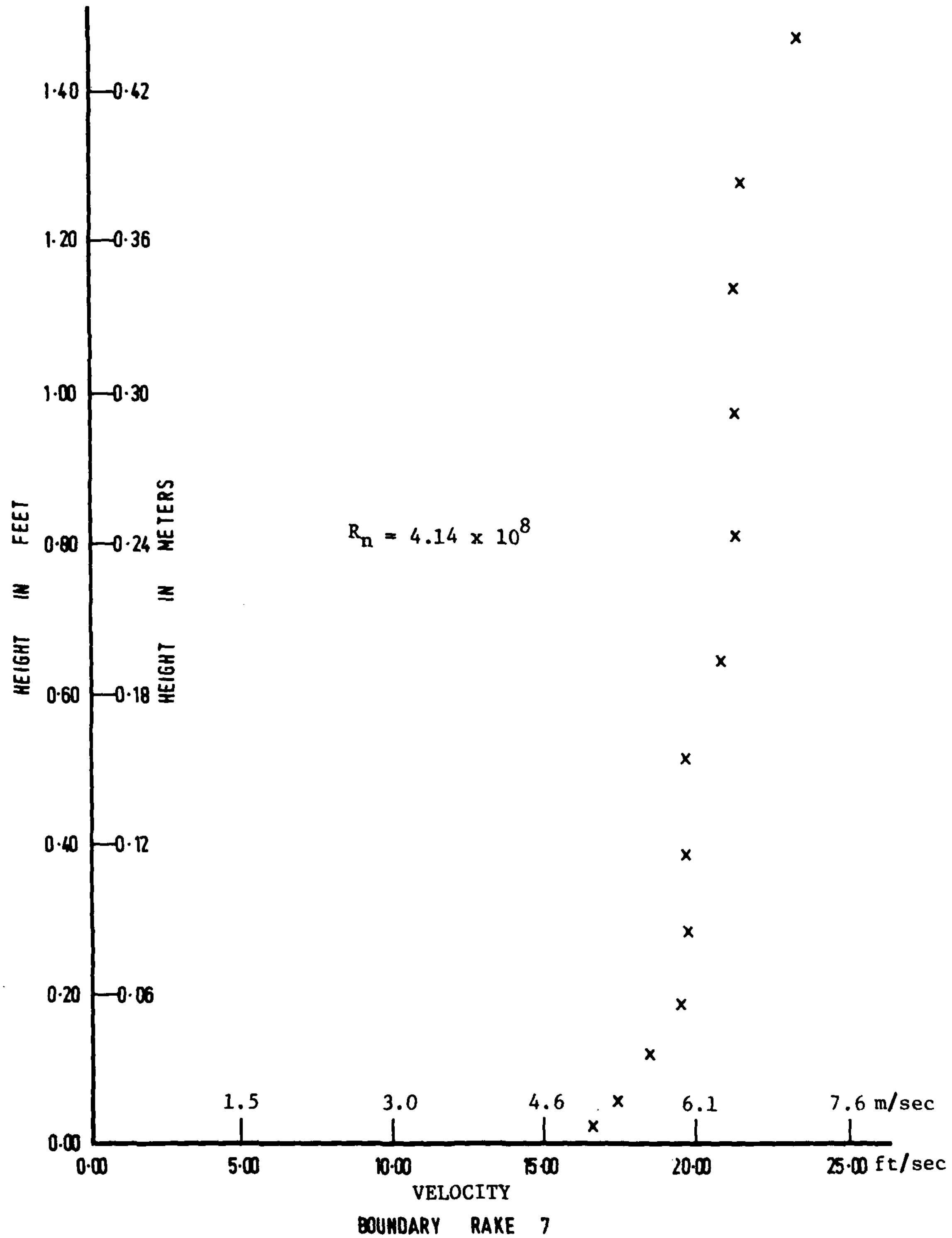


Figure 51 - Boundary Layer Velocity Profile Measured on Rake 7 at a Speed of 24.98 Ft/Sec (7.61 m/sec)

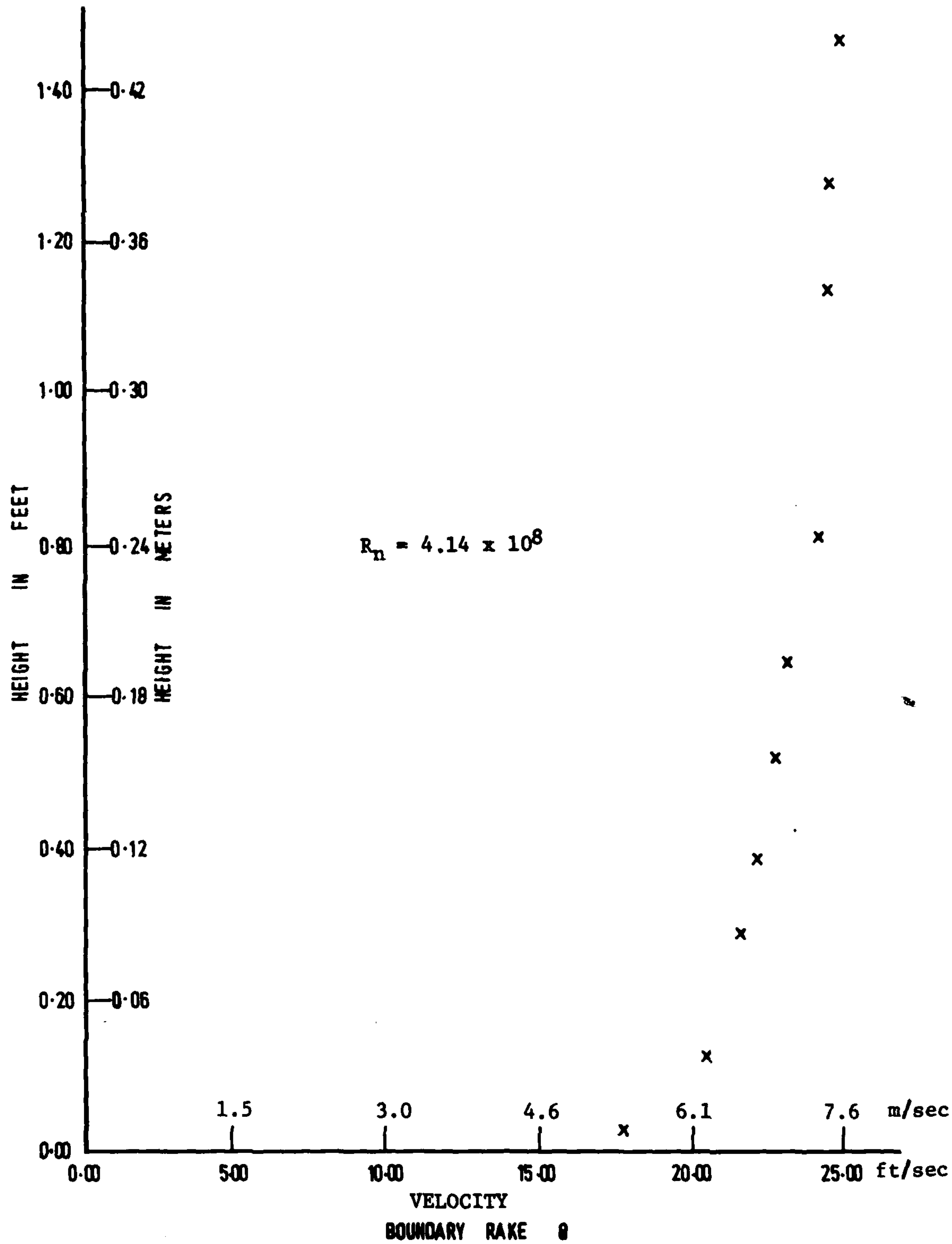


Figure 52 - Boundary Layer Velocity Profile Measured on Rake 8 at a Speed of 24.98 Ft/Sec (7.61 m/sec)

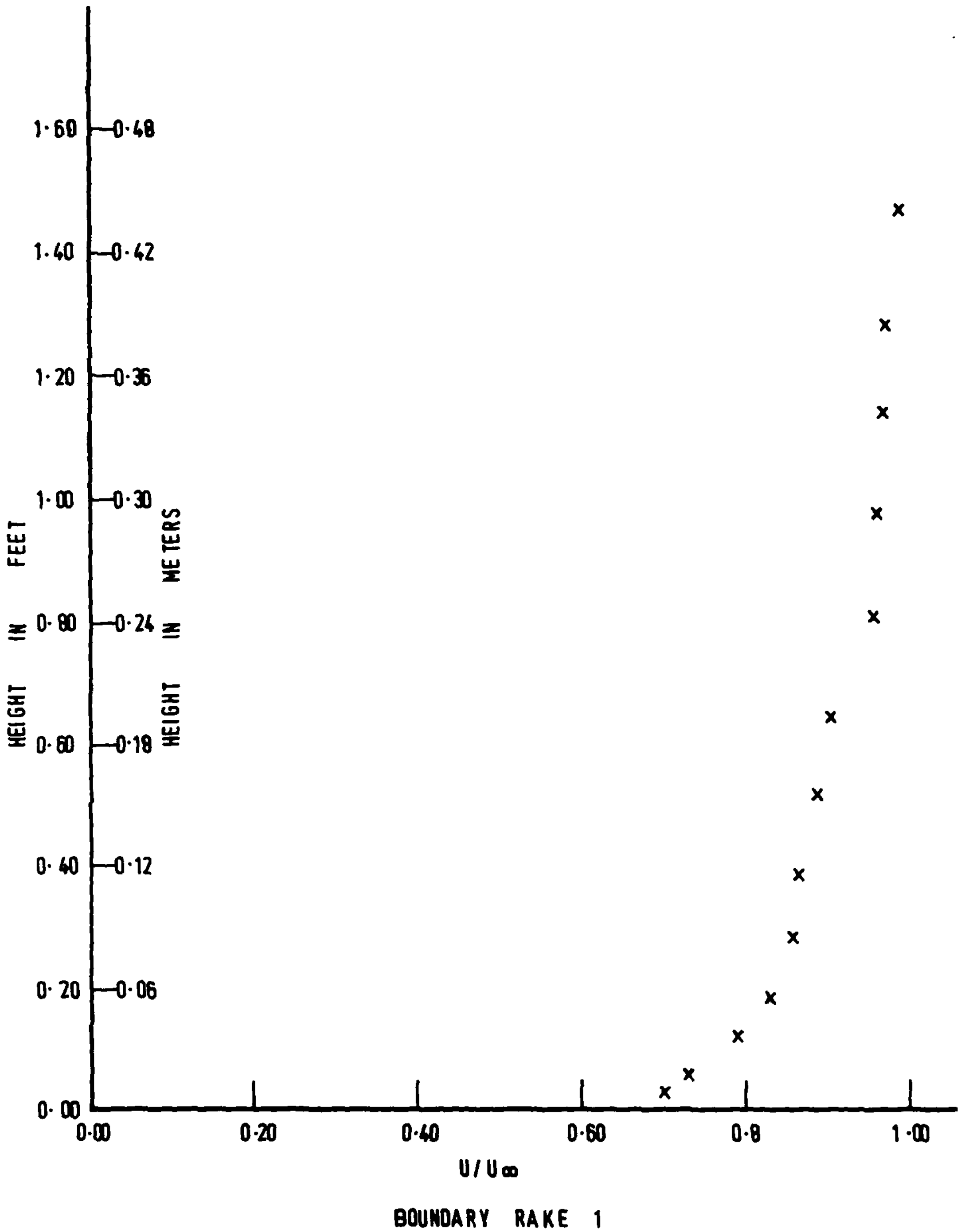


Figure 53 - Non-Dimensional Boundary Layer Velocity Profile of Rake 1

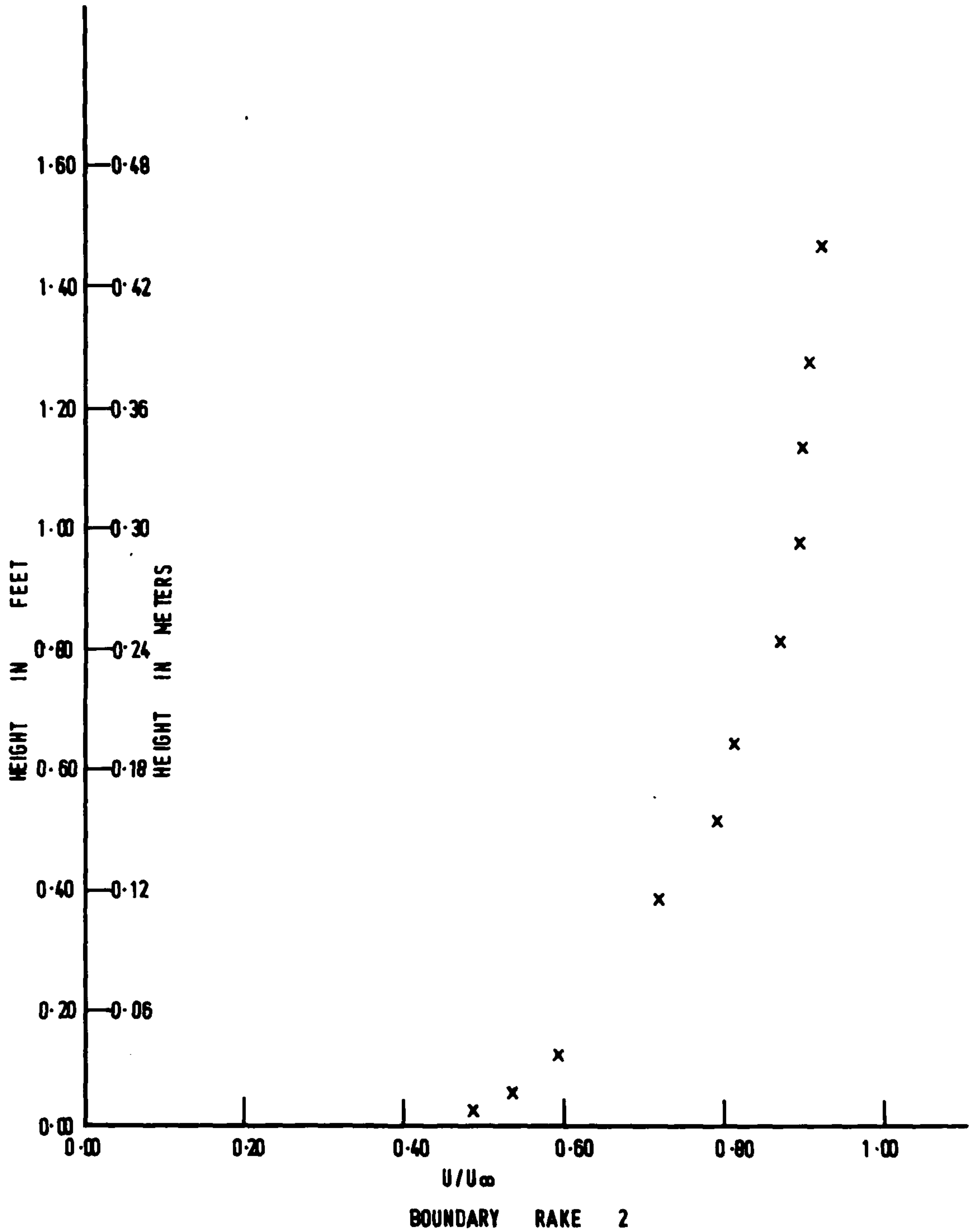


Figure 54 - Non-Dimensional Boundary Layer Velocity Profile of Rake 2

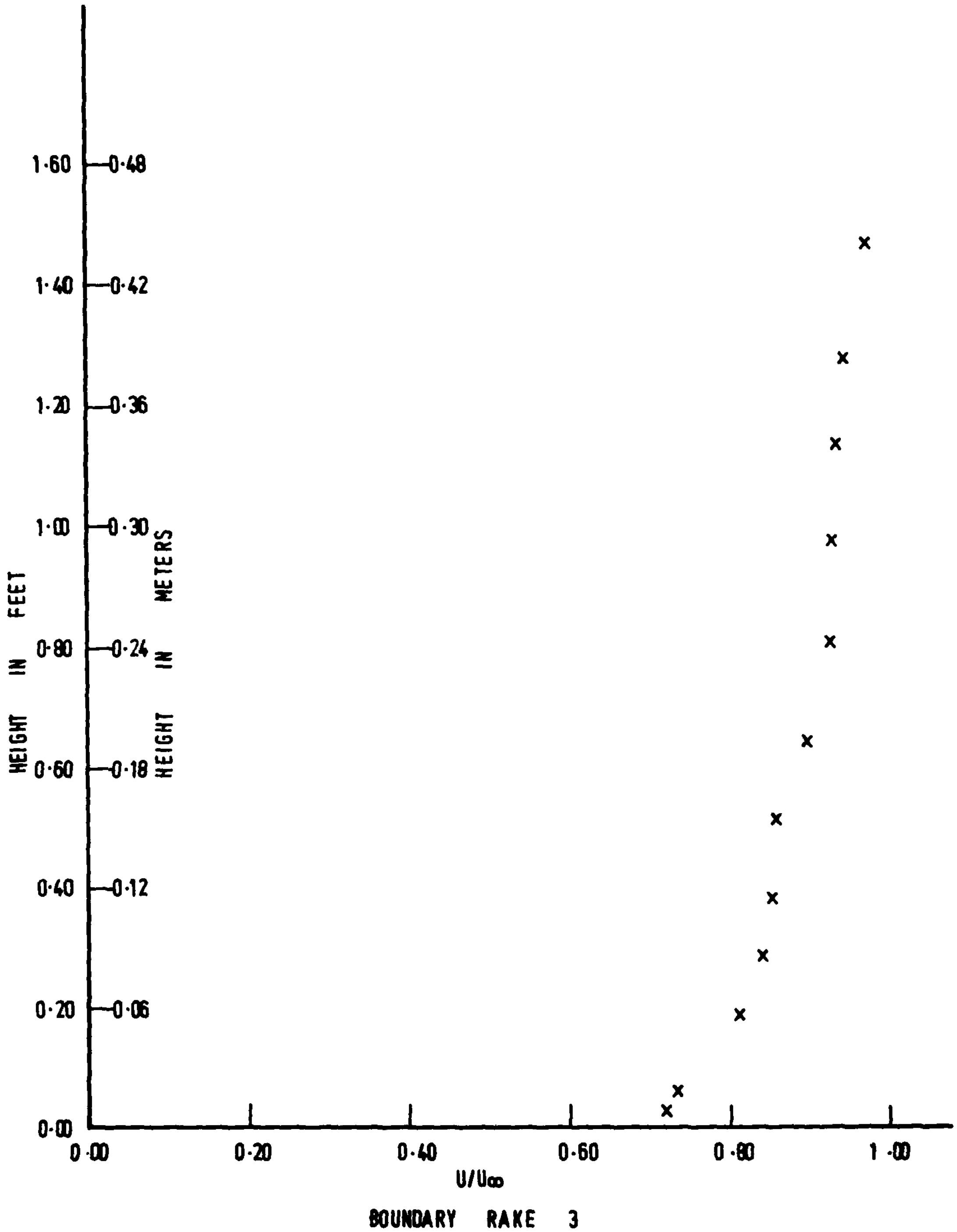


Figure 55 - Non-Dimensional Boundary Layer Velocity Profile of Rake 3

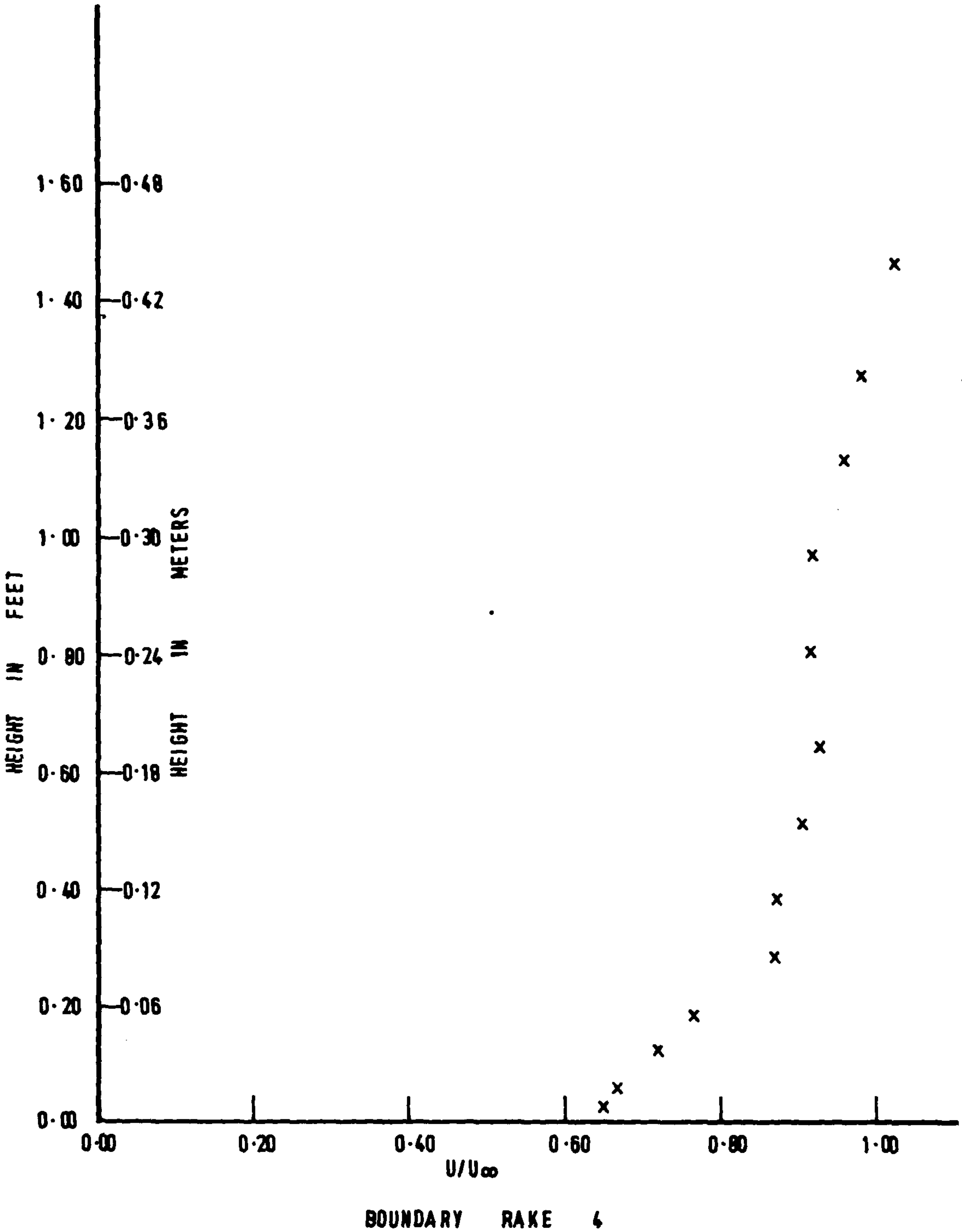


Figure 56 - Non-Dimensional Boundary Layer Velocity Profile of Rake 4

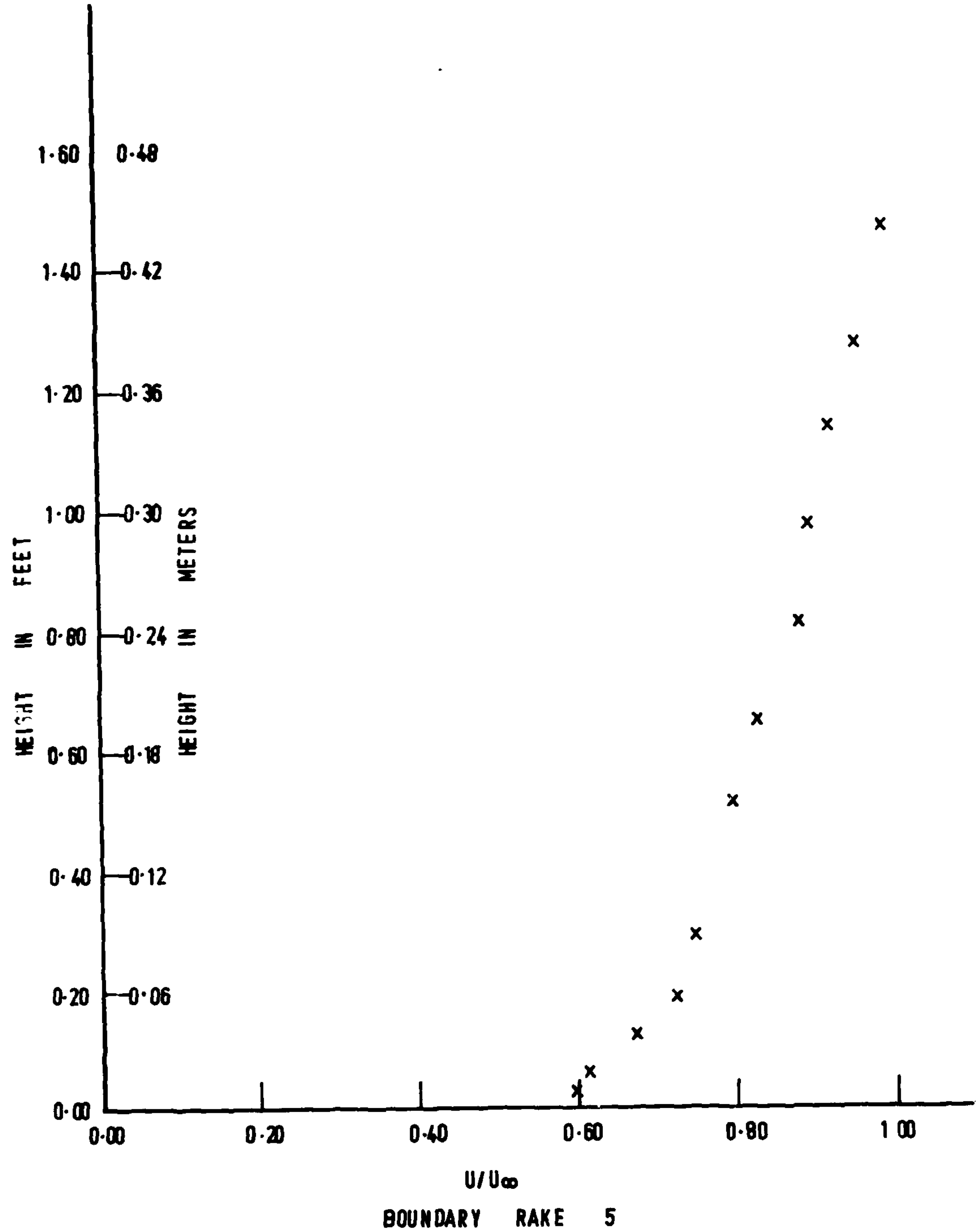


Figure 57 - Non-Dimensional Boundary Layer Velocity Profile of Rake 5

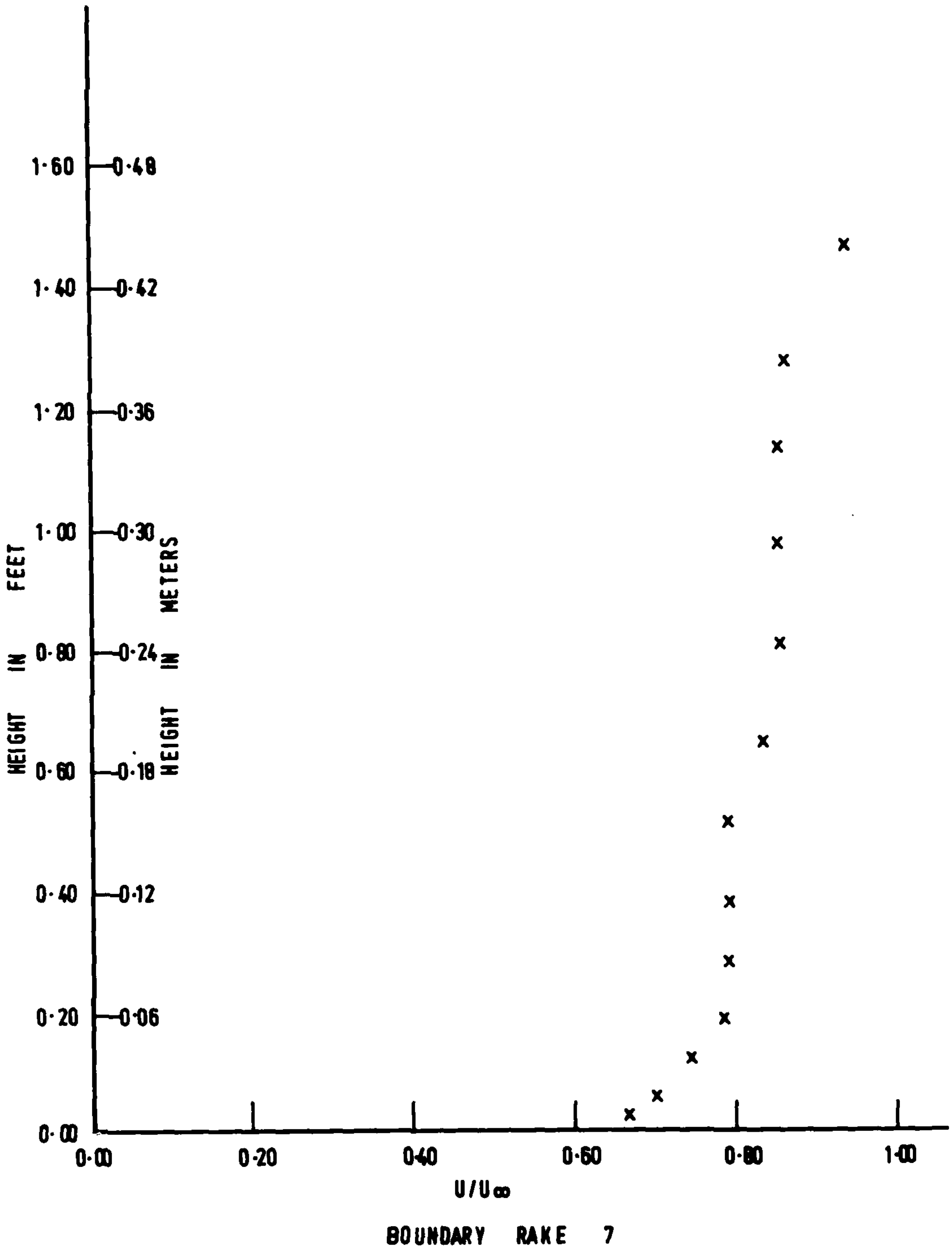


Figure 58 - Non-Dimensional Boundary Layer Velocity Profile of Rake 7

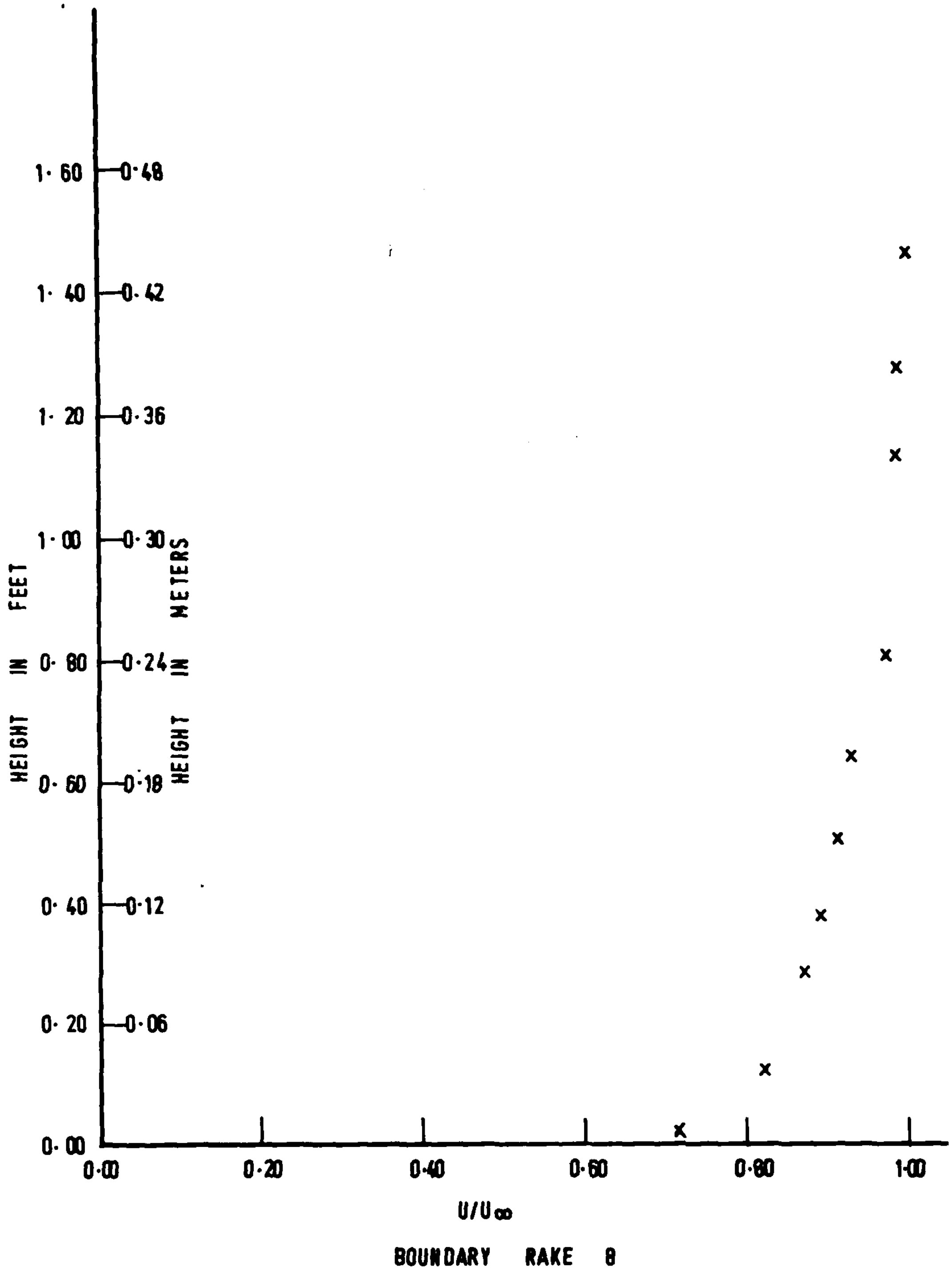


Figure 59 - Non-Dimensional Boundary Layer Velocity Profile of Rake 8

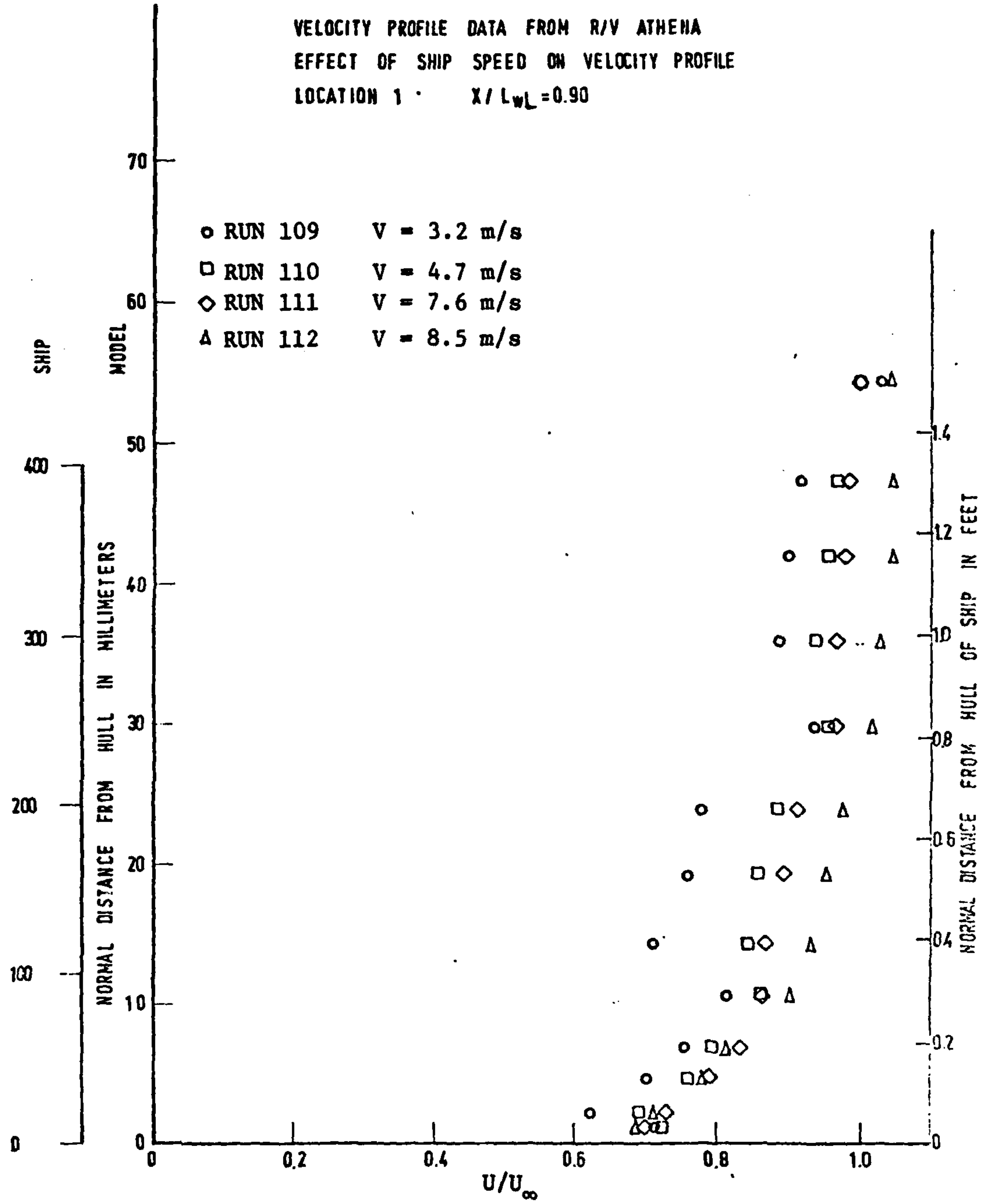


Figure 60 - Effect of Ship Speed on Velocity Profile of Rake 1

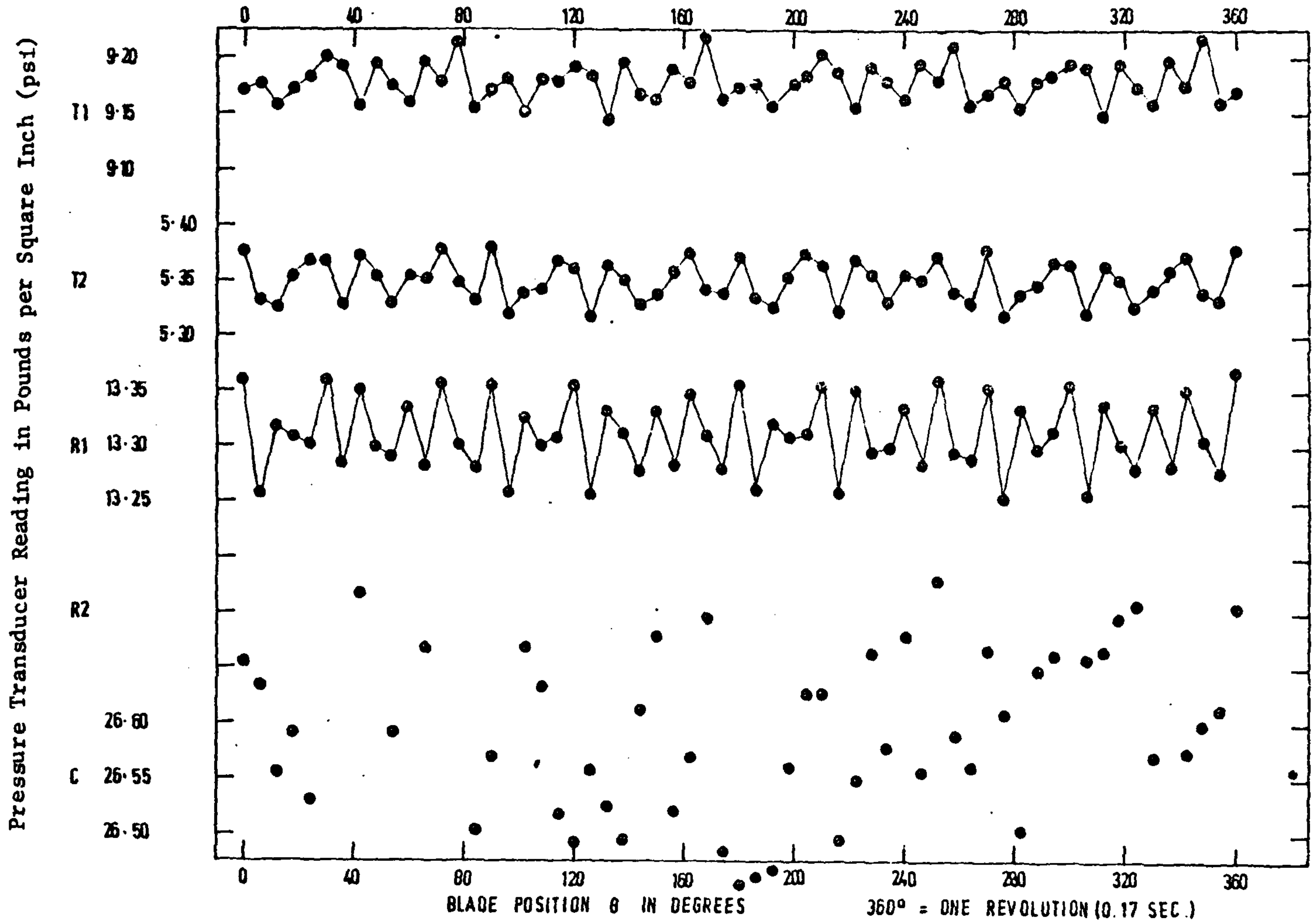


Figure 61 - Average Pressures From Each Pressure Transducer as a Function of Angular Position (Run 205, 345 rpm)

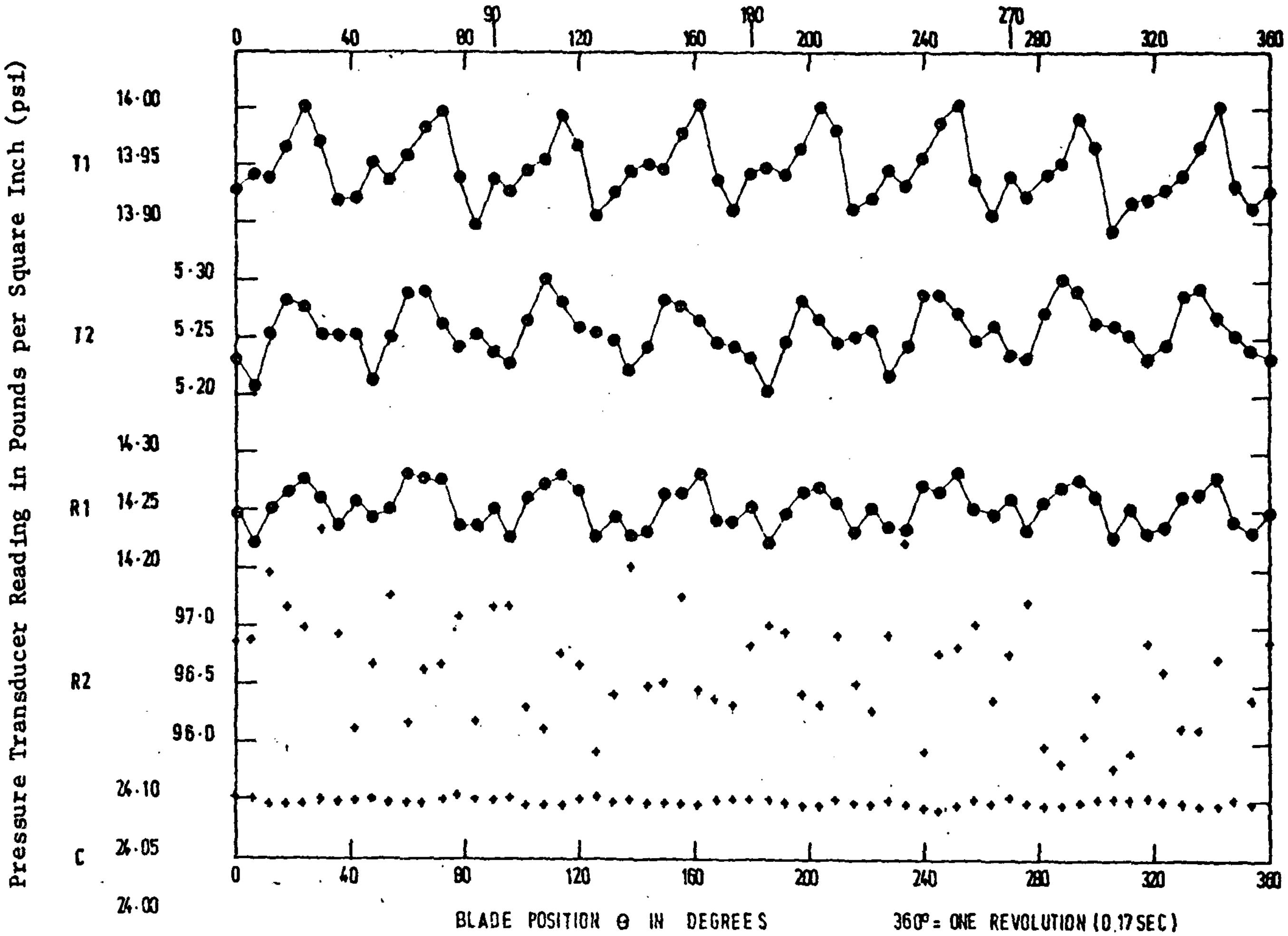


Figure 62 - Average Pressures From Each Pressure Transducer as a Function of Angular Position (Run 209, 345 rpm)

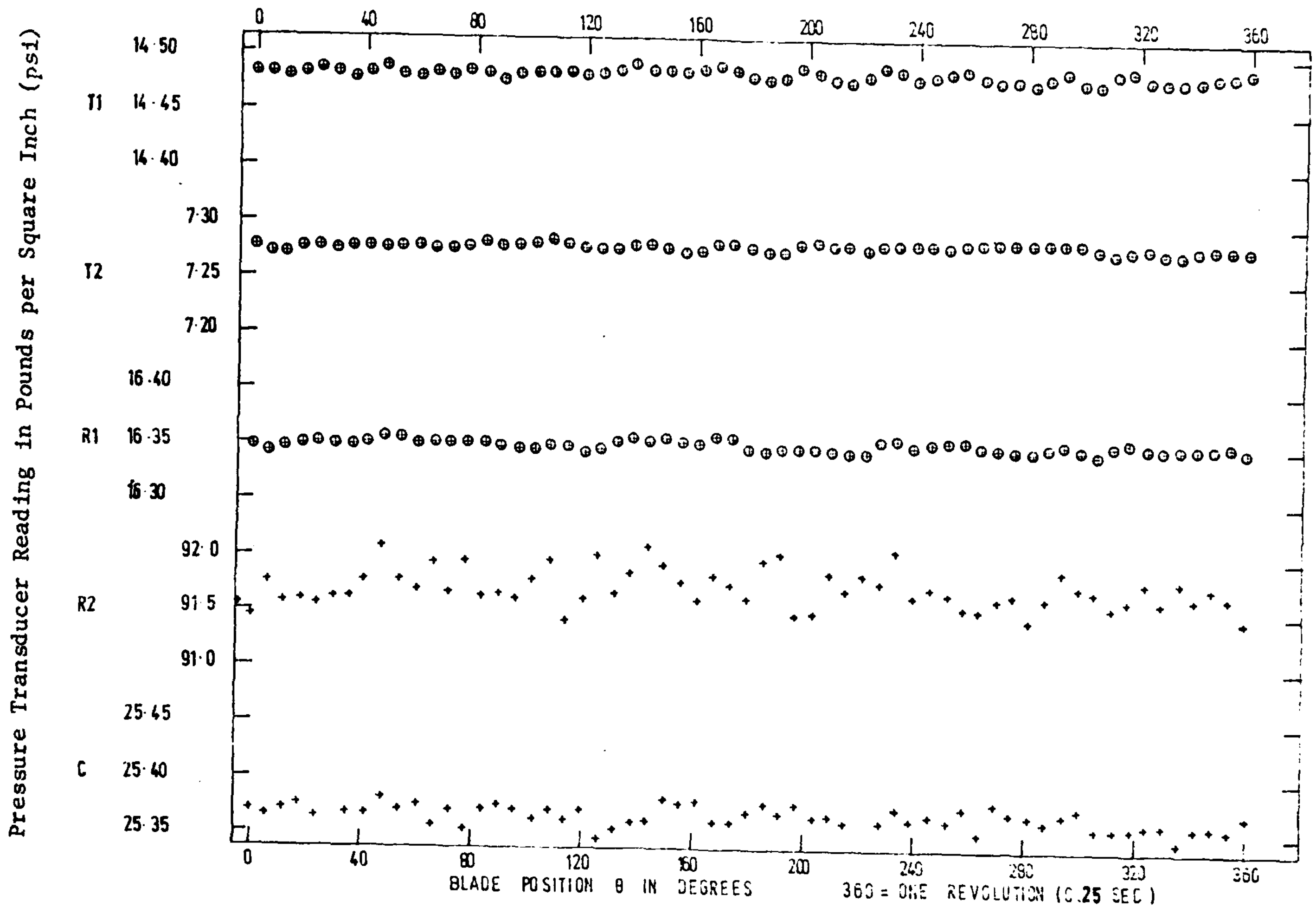


Figure 63 - Average Pressures From Each Pressure Transducer as a Function of Angular Position (Run 208, 240 rpm)

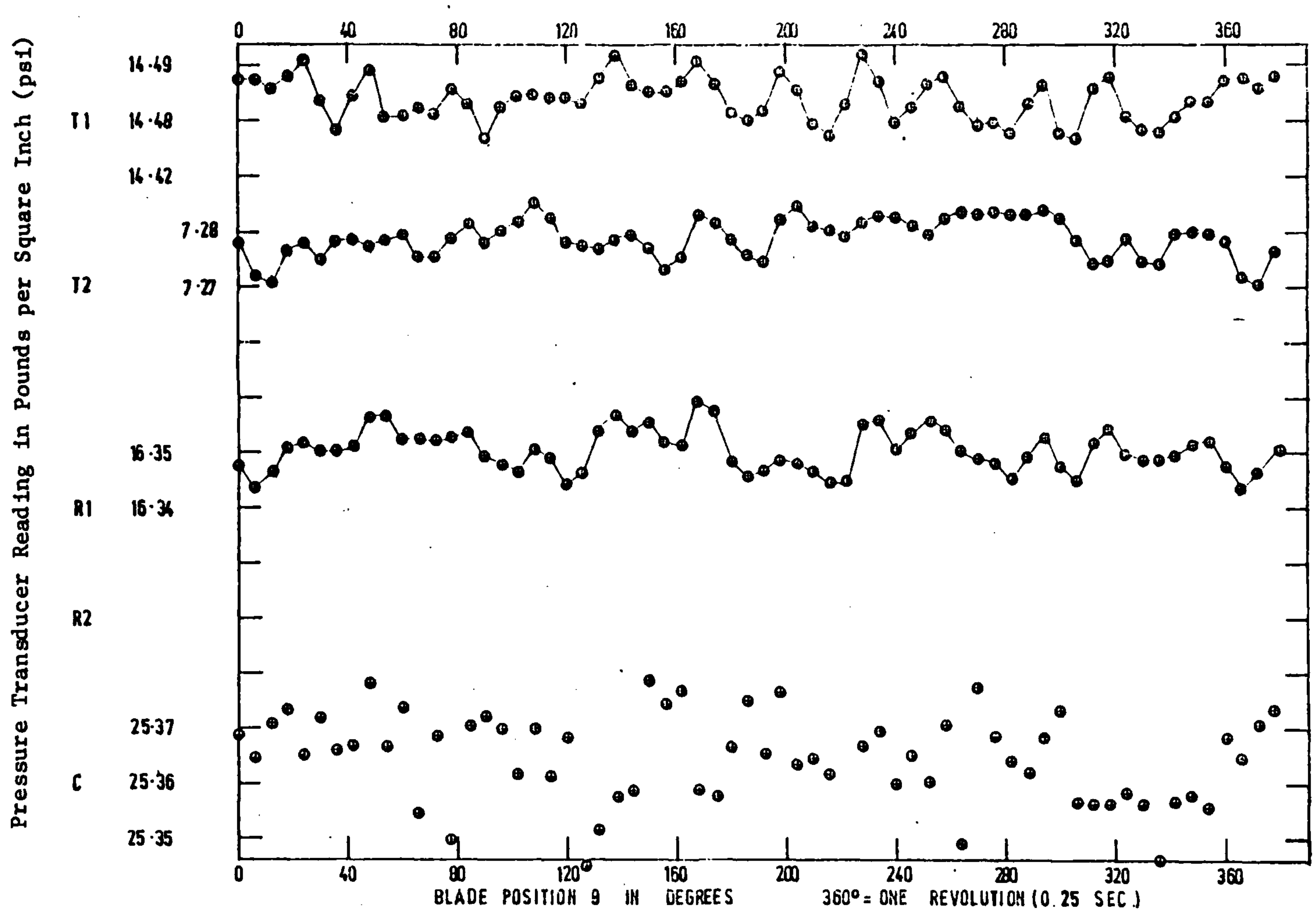


Figure 64 - Expanded Scale of Average Pressure from Figure 61 (Run 208, 240 rpm)

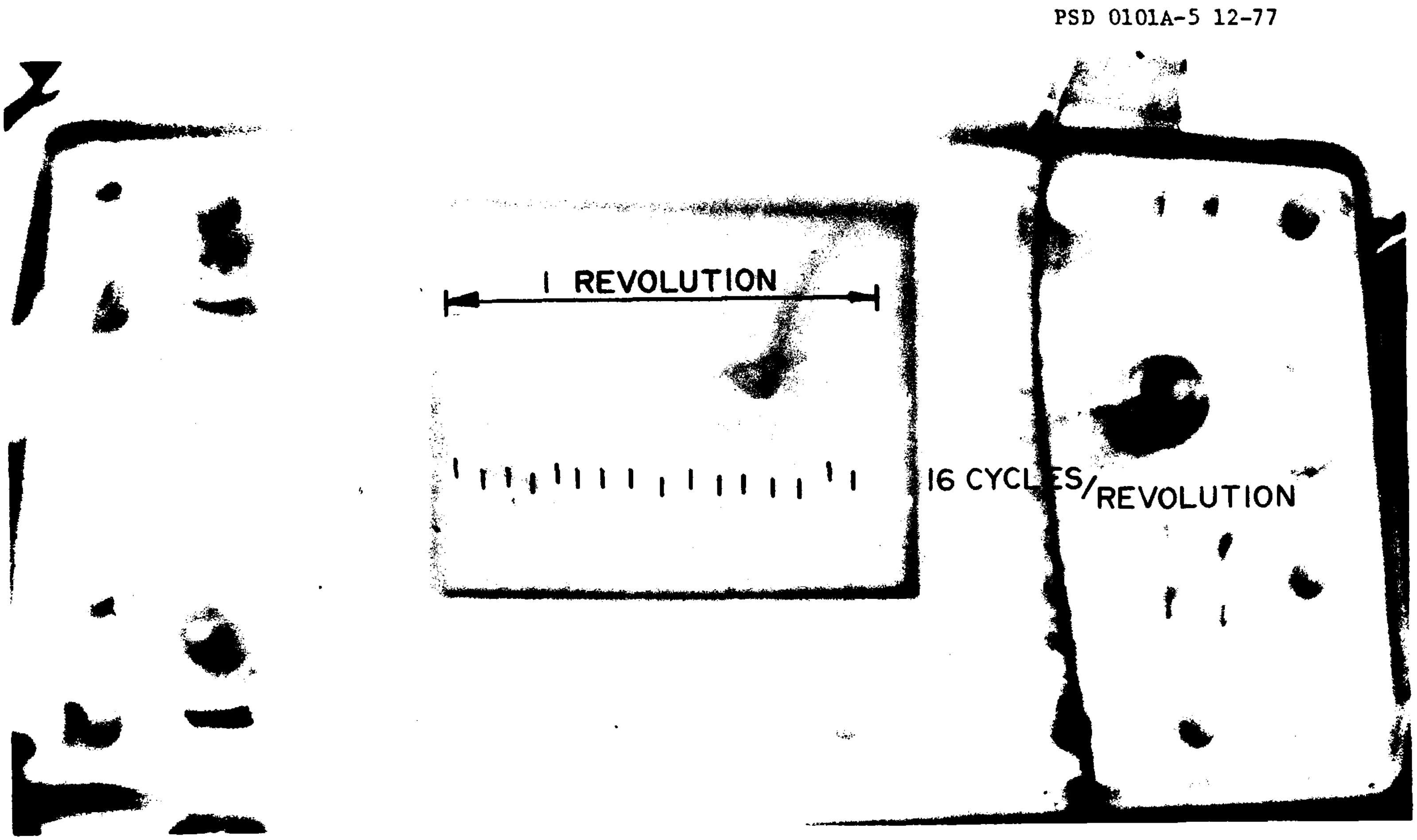


Figure 65 - Oscilloscope Trace of Signal from Piezoelectric Pressure Gage on Port Shaft Ahead of Propeller

TABLE 1

FULL-SCALE TRIAL AGENDA

Experiment number	Run numbers	Nominal Speed(s)		Date	Measurements
1	12-33	9 kts	4.63 m/s	4,5 Sep 77	Velocity Components in 3 Planes
	34-61	15 kts	7.72 m/s	5,6,8 Sep 77	Velocity Components in 3 Planes
2	62-77	15 kts	7.72 m/s	9 Sep 77	Velocity Components in 1 Plane
3	101-112	6 kts	3.09 m/s	11 Sep 77	Boundary Layer Velocity Profile
		9 kts	4.63 m/s		
		15 kts	7.72 m/s		
		17 kts	8.75 m/s		
4	201-209	9 kts	4.63 m/s	13 Sep 77	Time-varying pressures ahead of
		15 kts	7.72 m/s		Propeller disk

(Run numbers not used: 78-100 and 113-200, inclusive)

TABLE 2

R/V ATHENA FULL-SCALE WAKE SURVEY TRIAL CONDITIONS

Date	Experi-ment	Run Number	0800 Barometer		0800 Wind Direction	0800 Wind Strength	Sea Conditions		Air Temperature		1500 Water Temperature		Draft Forward		Draft Aft	
			Inch of Mercury	Kilo-pascals		Knots	Feet	Meters	Fahrenheit	Celsius	Fahrenheit	Celsius	Feet	Meters	Feet	Metem
Diesel Mode - 3 rakes																
4 Sep	1	12-24	30.00	101.3	-	0	2-4	0.6-1.2	84	28.9	82	27.8	5.33	1.63	5.83	1.78
5 Sep	1	25-33	29.60	100.0	-	0	0-1	0.0-0.3	-	-	83	28.3	5.33	1.63	5.83	1.78
Turbine Mode - 3 rakes																
5 Sep	1	34-43	29.60	100.0	-	0	0-1	0.0-0.3	-	-	83	28.3	5.33	1.63	5.83	1.78
6 Sep	1	44-48	29.60	100.0	-	0	0-1	0.0-0.3	-	-			5.33	1.63	5.92	1.80
8 Sep	1	49-61	29.96	101.2	SW	4-6	1-2	0.3-0.6	-	-	83	28.3	5.42	1.65	5.92	1.80
													5.33	1.63	5.75	1.75
Turbine Mode - 1 rake																
9 Sep	2	62-77	29.94	101.1	SW	2-4	0-0	0.0-0.0	-	-	83	28.3	5.33	1.63	5.92	1.80
Turbine Mode - Boundary Layer Probes																
11Sep	3	101-112	29.98	101.2	NW	4-6	0-0	0.0-0.0	-	-	85	29.4	5.33	1.63	5.83	1.78
Turbine Mode - Piezoelectric Tube																
13Sep	4	201-209	30.05	101.5	E	6-10	2-4	0.6-1.2	-	-	85	29.4	5.33	1.63	5.92	1.80

APPENDIX A

VISUALLY READ DATA FROM SHIP INSTRUMENTATION

Units are presented as the original data were recorded.

Speeds are given in knots.

Angles are given in degrees.

Wind speed and direction are relative to the ship.

Propeller pitch is the ratio of the actual setting to the maximum pitch setting of the propeller.

TABLE A-1 - VISUALLY READ DATA FROM SHIP INSTRUMENTATION

Run No.	Time	Rudder Angle	Roll Angle	Pitch Angle	Course	RPM	Kenyon Speed	Knotmeter Speed	Wind Speed	Wind Direction	Prop. Pitch	Sea State	Stbd Rake	Port Rake	Comments
								4 September 1977							
16	1406	4L	±6	±3	176	240	9.2	8.7	16	300		1			
17	1431	3L	±7	±1	356	240	9.0	9.1	8	070		1			Abort
18	1515	3L	±3	±1	356	240	9.0	9.2	6	070		1			
19															Abort
19	1635	5L	±1	±1	275	237	8.5	8.0	8	270		1			
20	1656	3L	±2	0	260	240	9.5	9.4	12	270		1			
21	1708	3L	±3	0	265	240	9.6	9.5	10	270		1			
22	1712	2L	±3	0	265	241	9.3	9.3	10	270		1			
23	1735	1R	±3	±2	085	241	9.0	9.0	20	040		1			
24	1751	5L	±3	±1	260	238	9.5	9.4	10	270		1			
								5 September 1977							
25	0859	2L	±2	±1	102	242	8.6	8.4	5	060		0-1	240	140	
26															NO DATA
27	0929	2L	±3	±1	100	241	8.6	8.6	5	060		0-1	240	140	Knotmeter dropped 40'
28	0950	4L	±2	±2	100	240	8.7	7.8-9.3	6	040		0-1	220	120	
29	1014	4L	±1	±2	100	240	8.8	8.5-9.7	5	045		0-1	200	100	
30	1020	3.5L	±2	±1	280	238	8.6	8.3	10	330		0-1	160	80	
31	1101	2.5L	±5	±1	180	239	8.5	7.4-8.7	10	040		0-1	120	70	
32	1127	2.5L	±3	±1	180	242	8.7	8.9-9.3	10	030		0-1	120	70	

TABLE A-1 (CONTINUED)

Run No.	Time	Rudder Angle	Roll Angle	Pitch Angle	Course	RPM	Kenyon Speec	Knotmeter Speed	Wind Speed	Wind Direction	Prop. Pitch	Sea State	Stbd Rake	Port Rake	Comments
33	1148	3L	±5	±0	0	240	8.9	8.9-9.9	10	330		0-1	100	60	
34	1300	2.5L	±1	±0	100	346	14.7	14.3-16.0	14	380	.9	0-1	240	240	
35	1336	2.5L	±2	±0	280	350	14.6	15.1-15.3	10	020	.94	0-1	220	220	
36	1359	2.5L	±1	0	280	345	15.1	14.6	12	045	.98	0-1	200	200	
37	1431	2.5L	±2	±2	100	343	14.7	14.6	18	330	.95	0	180	180	Stbd list 1°
38	1500	5L	±1	0	280	346	15.2	15.0	8	030	.97	0	160	160	Stbd list 1°
39	1527	4L	±1	±2	100	344	14.8	13.9-15.4	18	330	.98	0	140	140	Stbd list 1°
40	1548	4L	±1	0	285	347	15.3	14.0-15.2	8	020	.98	0	120	120	Stbd list 1°
41	1624	3.5L	±1	0	280	349	15.0	14.0-15.1	8	030	.98	0	100	100	Abort
42	1630	4L	±1	0	300	345	15.0	14.0-15.0	6	010	.98	0	100	100	
43	1640	5L	±1	0	300	345	15.2	15.2	6	050	.98	0	100	100	
								6 September 1977							
44	0850	4L	±1	±1	110	352	14.9	13.9-15.3	8	020	.96	0	100	100	
45	0856	4L	±1	±1	110	354	14.7	14.9	8	020	.96	0	100	100	
46															No record on bridge
47	1125	4L	±1	0	284	344	14.5	13.9-14.3	15	020	.95	0	100	100	
47A	1143	5L	±1	±1	105	345	14.4	14.1-14.,	15	330	.95	0	100	100	Stbd list 1.5°
48	1207	3.5L	±1	±1	110	351	14.6	13.9-14.9	14	340	.95	0	80	80	Stbd list 1.5°
								8 September 1977							
49	1351	2L	±1	±2	110	345	14.3	13.7-14.9	17	055	.94	0-1	80	80	Stbd list 1°
50	1415	3L	±1	±2	110	349	15.1	13.9-16.3	15	050	.98	1	60	60	Stbd list 1°

TABLE A-1 (CONTINUED)

Run No.	Time	Rudder Angle	Roll Angle	Pitch Angle	Course	RPM	Kenyon Speed	Knotmeter Speed	Wind Speed	Wind Direction	Prop. Pitch	Sea State	Stbd Rake	Port Rake	Comments
51	1435	3L	±1	±3	110	345	15.0	14.3-16.0	17	040	.98	1	40	40	Stbd list 1°
52	1459	3.5L	±2	±2	160	345	14.4	14.3-15.7	21	025	.98	1	20	20	Speed dropped 7 knots
53	1529	2.5L	±2	±2	160	344	14.8	14.0-15.3	21	030	.96	1-2	10	10	
54	1550	3L	±2	±1	315	348	15.5	15.5	13	300	.98	1-2	30	30	Abort
55	1559	3L	±2	±1	315	349	14.7-15.1	14.5	13	300	.98	1-2	30	30	Abort
56	1614	4L	±1	±1	315	350	15.0	14.8	12	310	.99	1-2	30	30	
57	1638	3.5L	±1	0	310	345	15.0	14.8	20	010	.96	1	50	50	
58	1657	3.5L	±1	±1	335	350	15.1	14.5-15.9	20	330	.97	1	90	90	
59	1715	4L	±2	±2	0	349	15.2	14.2-15.1	17	325	.97	1	130	130	
60	1737	3L	±4	±1	180	345	14.9	14.3-15.3	13	030	.96	1	210	210	
61	1759	3L	±1	±1	305	350	15.2	14.5	13	340	.97	1	230	230	
								9 September 1977							
62	1410	3L	±1	±1	105	345	14.9	14.9-15.3	3	065	.98	1	230	230	No list
63	1429	3L	±1	±2	105	342	14.8	14.3-15.9	6	020	.98	1	220	220	
64	1445	3L	±1	±1	105	341	15.0	14.7-15.9	6	020	1.0	1	210	210	
65	1456	3L	±1	±1	105	341	15.1	14.3-16.0	6	020	1.0	1	210	210	
66	1514	2.5L	±2	±1	285	341	14.8	14.3-14.9	16	034	.98	1	170	170	
67	1537	3.5L	±1	±1	285	348	15.1	14.3-15.9	18	000	.98	1	130	130	
68	1557	4L	0	±2	105	346	15.1	14.5-15.0	10	350	.99	1	90	90	

TABLE A-1 (CONTINUED)

Run No.	Time	Rudder Angle	Roll Angle	Pitch Angle	Course	RPM	Kenyon Speed	Knotmeter Speed	Wind Speed	Wind Direction	Prop. Pitch	Sea State	Stbd Rake	Port Rake	Comments
69	1625	4L	±2	±2	105	349	15.2	14.9-15.9	16	020	1.1	1	70	70	
70	1641	3.5L	±2	±1	285	341	14.9	14.9-15.5	12	340	1.1	0-1	60	60	Pitch high
71	1656	3L	±2	±1	285	346	14.9	14.4-15.3	10	340	.97	0-1	50	50	Pitch high
72	1716	3.5L	±1	0	285	352	15.4	15.1-15.9	10	020	.98	0-1	40	40	Stbd list 1°
73	1732	3L	±1	0	000	345	15.3	14.1-14.7	13	030	.97	0	30	30	Stbd list 1°
74	1747	3.5L	±.5	±1	000	342	15.2	14.3-14.9	11	030	.99	0	20	20	Stbd list 1°
75	1752	3.5L	0	±.5	000	341	15.3		11	30	.99	0	20	20	Stbd list 1°
76	1807	3.5L	±2	±1	250	342	15.0	14.7-15.5	11	320	.99	0	110	110	Stbd list 1°
77	1824	3.5L	±1	±1	245	342	15.1	14.1-15.6	13	330	.99	0	150	150	Stbd list 1°
								11 September 1977							
100	1223	3L	±1	0	359	242	8.5	8.3	10	025	.7	0			Stbd list 1°
100A	1241	3L	±1	0	179	242	8.5	8.7-9.7	8	330	.7	0			Stbd list 1°
101															NO DATA, 5 knot run
102	1323	3L	±0	0	359	241	8.8		9	040	.7	0			
103	1341	4L	±1	0	359	348	15.3	14.5	13	025	.98	0			
104	1357	3.5L	±1	0	179	349	14.4	14.4	14	330	.95	0			
105	1517	2.5L	0	0	179	263	8.5	8.5	10	300	.58	0			
106	1536	2.5L	0	0	359	347	15.2	15.2	16	035	.98	0			
107															Abort, vibration

TABLE A-1 (CONTINUED)

Run No.	Time	Rudder Angle	Roll Angle	Pitch Angle	Course	RPM	Kenyon Speed	Knotmeter Speed	Wind Speed	Wind Direction	Prop. Pitch	Sea State	Stbd Rake	Port Rake	Comments
108	1643	4L	0	0	179	348	15.1	14.9-15.7	18	315	.98	0			Turbine vibration, abort
109	1532	3L	0	0	020	191-194	5.5	5.1-5.7	8	050	.44	0			RPM governed by hand NG
109A	1739	3L	0	0	020	210-215	6.0	5.5-6.1	8	050	.45	0			
110	1748	3L	0	0	020	245-258	8.7	8.4-9.5	10	030	.68	0			
111	1802	4L	0	0	010	347	14.9	14.4-15.2	14	025	.96	0			
112	1810	5L	±1	0	010	381	17.0	15.6-16.9	16	020	1.1	0			Brass knotmeter is in the wake at this speed
								13 September 1977							
201	1127														Measured mile run
202	1141														Measured mile run
203	1200	3L	±2	±6	080	349	14.6	15.0	20	015	.98	2-3			
204	1216	3L	±3	±5	080	240	8.7-9.2	5.5-10.3	16	015	.82	2-3			
205	1231	3L	±3	±5	080	353	15.4	14.5-17.1	20	000	.98	2-3			
206	1244	3L	±3	±3	080	238	8.6	7.9-9.4	16	010	.81	2-3	230		
207	1255	3.5L	±3	±5	080	348	14.8	13.3-15.7	20	010	1.0	2-3	230		
208	1315	4L	±1	±1	275	238	9.3-10.1	8.9-9.9	2	030	.82	2	260		
209	1337	4L	±1	±1	275	341-349	15-15.3	14.7-15.7	8	030	.92	2	260		

APPENDIX B

VELOCITY COMPONENT RATIOS FROM EXPERIMENT 1

Units are presented as the original data were recorded.

Speeds are given in feet per second.

Angles are given in degrees.

TABLE B-1 - VELOCITY COMPONENT RATIOS FROM RUNS 12-61

RUN 12

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	14.502	130.0	1.074	-0.075	0.051
2	14.502	130.0	1.484	-0.073	-0.131
3	14.502	130.0	0.000	0.000	0.000
4	14.502	130.0	0.682	-0.000	-0.091
5	14.502	310.0	0.000	0.000	0.000
6	14.502	310.0	0.000	0.000	0.000
7	14.502	310.0	0.665	0.177	0.219
8	14.502	310.0	0.507	0.014	-0.197
9	14.502	220.0	0.000	0.000	0.000
10	14.502	220.0	0.000	0.000	0.000
11	14.502	220.0	0.505	-0.077	0.000
12	14.502	40.0	0.669	0.066	-0.166
13	14.502	40.0	0.526	-0.000	-0.170
14	14.502	40.0	0.000	0.000	0.000
15	14.502	40.0	0.000	0.000	0.000
16	14.502	40.0	0.739	0.346	-0.099
17	14.502	40.0	0.000	0.000	0.000
18	14.502	100.0	0.000	0.000	0.000
19	14.502	100.0	0.473	-0.188	0.006
20	14.502	100.0	0.000	0.000	0.000
21	14.502	280.0	0.000	0.000	0.000
22	14.502	280.0	0.000	0.000	0.000
23	14.502	280.0	0.507	0.233	-0.008
24	14.502	280.0	0.893	0.071	-0.112
25	14.502	280.0	0.000	0.000	0.000
26	14.502	280.0	0.000	0.000	0.000

TABLE B-1 (CONTINUED)

RUN 14

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.079	130.0	0.966	-0.204	0.061
2	15.079	130.0	1.128	-0.102	0.028
3	15.079	130.0	0.963	-0.024	0.082
4	15.079	130.0	1.107	-0.161	-0.061
5	15.079	310.0	0.928	0.159	-0.125
6	15.079	310.0	1.107	0.162	-0.206
7	15.079	310.0	0.994	0.146	-0.129
8	15.079	310.0	0.910	0.194	-0.183
9	15.079	220.0	0.935	0.173	0.052
10	15.079	220.0	1.102	0.149	0.003
11	15.079	220.0	0.899	0.064	0.280
12	15.079	40.0	1.033	-0.095	-0.138
13	15.079	40.0	0.948	-0.273	-0.204
14	15.079	40.0	0.707	-0.216	-0.152
15	15.079	40.0	0.954	-0.180	-0.057
16	15.079	40.0	0.932	-0.074	-0.115
17	15.079	40.0	0.909	-0.219	-0.094
18	15.079	100.0	1.098	-0.171	-0.103
19	15.079	100.0	0.937	-0.195	0.070
20	15.079	100.0	0.950	-0.311	-0.004
21	15.079	280.0	0.000	0.000	0.000
22	15.079	280.0	1.205	0.096	0.128
23	15.079	280.0	0.906	0.226	-0.068
24	15.079	280.0	0.926	0.200	-0.107
25	15.079	280.0	0.983	0.293	-0.099
26	15.079	280.0	1.181	0.172	-0.155

TABLE B-1 (CONTINUED)

RUN 15

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.187	130.0	0.989	-0.121	0.059
2	15.187	130.0	0.997	-0.144	0.088
3	15.187	130.0	0.947	-0.157	0.108
4	15.187	130.0	1.120	-0.132	-0.002
5	15.187	310.0	0.982	0.219	-0.126
6	15.187	310.0	0.985	0.178	-0.166
7	15.187	310.0	1.043	0.165	-0.181
8	15.187	310.0	0.993	0.133	-0.167
9	15.187	220.0	0.938	0.188	0.024
10	15.187	220.0	0.993	0.183	0.069
11	15.187	220.0	0.934	0.058	0.171
12	15.187	40.0	0.981	-0.190	-0.151
13	15.187	40.0	0.977	-0.171	-0.158
14	15.187	40.0	0.890	-0.147	-0.122
15	15.187	40.0	0.958	-0.165	-0.158
16	15.187	40.0	0.808	-0.182	-0.164
17	15.187	40.0	0.926	-0.119	-0.086
18	15.187	100.0	0.935	-0.183	-0.004
19	15.187	100.0	1.040	-0.186	-0.015
20	15.187	100.0	0.952	-0.214	-0.005
21	15.187	280.0	0.000	0.000	0.000
22	15.187	280.0	0.957	0.113	0.234
23	15.187	280.0	0.989	0.222	-0.120
24	15.187	280.0	1.002	0.230	-0.134
25	15.187	280.0	1.004	0.216	-0.093
26	15.187	280.0	0.984	0.209	-0.118

TABLE B-1 (CONTINUED)

RUN 16

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	14.473	130.0	1.039	-0.112	0.107
2	14.473	130.0	1.026	-0.110	0.132
3	14.473	130.0	1.054	-0.070	0.137
4	14.473	130.0	1.364	-0.077	-0.148
5	14.473	310.0	1.032	0.141	-0.145
6	14.473	310.0	1.020	0.163	-0.192
7	14.473	310.0	1.036	0.146	-0.218
8	14.473	310.0	1.036	0.120	-0.224
9	14.473	220.0	1.012	0.238	0.004
10	14.473	220.0	1.029	0.224	0.017
11	14.473	220.0	1.067	0.023	0.201
12	14.473	40.0	0.978	-0.254	-0.143
13	14.473	40.0	1.044	-0.236	-0.105
14	14.473	40.0	1.011	-0.216	-0.110
15	14.473	40.0	1.026	-0.180	-0.109
16	14.473	40.0	0.989	-0.185	-0.106
17	14.473	40.0	1.048	-0.158	-0.083
18	14.473	100.0	0.981	-0.239	-0.034
19	14.473	100.0	1.063	-0.198	0.008
20	14.473	100.0	1.065	-0.236	0.002
21	14.473	280.0	0.000	0.000	0.000
22	14.473	280.0	0.976	0.116	0.245
23	14.473	280.0	1.081	0.228	-0.141
24	14.473	280.0	1.004	0.236	-0.137
25	14.473	280.0	0.980	0.179	-0.146
26	14.473	280.0	1.001	0.175	-0.113

TABLE B-1 (CONTINUED)

RUN 18

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.930	150.0	0.959	-0.145	0.056
2	15.930	150.0	1.042	-0.056	0.095
3	15.930	150.0	0.919	-0.011	0.104
4	15.930	150.0	0.548	-0.153	-0.403
5	15.930	330.0	0.728	0.072	-0.136
6	15.930	330.0	0.959	0.072	-0.160
7	15.930	330.0	0.959	0.078	-0.203
8	15.930	330.0	0.939	0.051	-0.194
9	15.930	240.0	0.946	0.220	-0.006
10	15.930	240.0	0.975	0.201	0.032
11	15.930	240.0	0.978	0.027	0.196
12	15.930	60.0	0.934	-0.220	-0.123
13	15.930	60.0	0.969	-0.200	-0.138
14	15.930	60.0	0.964	-0.209	-0.099
15	15.930	60.0	1.001	-0.190	-0.094
16	15.930	60.0	0.961	-0.192	-0.098
17	15.930	60.0	0.997	-0.165	-0.096
18	15.930	120.0	0.917	-0.164	0.030
19	15.930	120.0	0.996	-0.155	0.045
20	15.930	120.0	0.976	-0.164	0.070
21	15.930	300.0	0.000	0.000	0.000
22	15.930	300.0	0.983	0.171	0.166
23	15.930	300.0	1.010	0.173	-0.182
24	15.930	300.0	0.965	0.179	-0.182
25	15.930	300.0	0.913	0.163	-0.159
26	15.930	300.0	0.835	0.143	-0.147

TABLE B-1 (CONTINUED)

RUN 19

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	14.003	170.0	1.024	0.073	0.111
2	14.003	170.0	1.052	0.050	0.139
3	14.003	170.0	1.007	0.049	0.149
4	14.003	170.0	1.408	0.040	-0.282
5	14.003	350.0	0.833	0.002	-0.045
6	14.003	350.0	0.942	-0.002	-0.071
7	14.003	350.0	1.025	-0.015	-0.110
8	14.003	350.0	0.965	0.001	-0.185
9	14.003	260.0	0.986	0.252	-0.073
10	14.003	260.0	1.022	0.237	-0.066
11	14.003	260.0	1.024	0.049	0.227
12	14.003	80.0	0.968	-0.25[illegible]	-0.072
13	14.003	80.0	0.986	-0.240	-0.058
14	14.003	80.0	0.978	-0.235	-0.012
15	14.003	80.0	1.041	-0.200	-0.035
16	14.003	80.0	0.966	-0.206	-0.026
17	14.003	80.0	1.027	-0.184	-0.028
18	14.003	80.0	0.967	-0.234	-0.140
19	14.003	80.0	1.016	-0.229	-0.102
20	14.003	80.0	1.030	-0.235	-0.103
21	14.003	260.0	0.000	0.000	0.000
22	14.003	260.0	1.024	0.016	0.248
23	14.003	260.0	1.000	0.248	0.012
24	14.003	260.0	1.009	0.255	-0.000
25	14.003	260.0	1.033	0.236	0.017
26	14.003	260.0	1.045	0.198	0.019

TABLE B-1 (CONTINUED)

RUN 20

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.230	190.0	1.033	0.166	0.105
2	15.230	190.0	1.057	0.165	0.115
3	15.230	190.0	1.038	0.171	0.124
4	15.230	190.0	1.237	0.131	-0.094
5	15.230	10.0	0.841	-0.044	-0.195
6	15.230	10.0	1.064	-0.084	-0.155
7	15.230	10.0	1.029	-0.094	-0.198
8	15.230	10.0	1.079	-0.104	-0.196
9	15.230	280.0	1.013	0.241	-0.138
10	15.230	280.0	1.015	0.223	-0.146
11	15.230	280.0	1.004	0.134	0.231
12	15.230	100.0	0.972	-0.237	0.002
13	15.230	100.0	1.040	-0.222	0.028
14	15.230	100.0	1.004	-0.227	0.009
15	15.230	100.0	0.999	-0.170	0.044
16	15.230	100.0	0.999	-0.181	0.022
17	15.230	100.0	1.067	-0.161	0.046
18	15.230	60.0	1.034	-0.219	-0.197
19	15.230	60.0	0.994	-0.245	-0.185
20	15.230	60.0	0.987	-0.232	-0.144
21	15.230	240.0	0.000	0.000	0.000
22	15.230	240.0	1.030	-0.062	0.217
23	15.230	240.0	1.001	0.213	0.070
24	15.230	240.0	1.037	0.195	0.083
25	15.230	240.0	1.013	0.176	0.082
26	15.230	240.0	1.076	0.161	0.089

TABLE B-1 (CONTINUED)

RUN 22

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.952	210.0	1.000	0.214	0.069
2	15.952	210.0	1.027	0.198	0.069
3	15.952	210.0	0.991	0.184	0.088
4	15.952	210.0	1.087	0.188	-0.014
5	15.952	30.0	0.904	-0.234	-0.143
6	15.952	30.0	0.000	0.000	0.000
7	15.952	30.0	0.866	-0.040	-0.092
8	15.952	30.0	0.986	-0.028	-0.126
9	15.952	300.0	0.934	0.195	-0.212
10	15.952	300.0	0.987	0.183	-0.183
11	15.952	300.0	0.980	0.158	0.181
12	15.952	120.0	0.886	-0.175	0.067
13	15.952	120.0	0.982	-0.189	0.061
14	15.952	120.0	0.964	-0.175	0.073
15	15.952	120.0	0.988	-0.119	0.083
16	15.952	120.0	0.987	-0.095	0.074
17	15.952	120.0	0.990	-0.105	0.102
18	15.952	40.0	0.883	-0.182	-0.203
19	15.952	40.0	0.781	-0.269	-0.258
20	15.952	40.0	1.010	-0.178	-0.176
21	15.952	220.0	0.000	0.000	0.000
22	15.952	220.0	0.970	-0.107	0.125
23	15.952	220.0	0.968	0.126	0.107
24	15.952	220.0	1.023	0.135	0.107
25	15.952	220.0	1.014	0.114	0.123
26	15.952	220.0	1.042	0.106	0.108

TABLE B-1 (CONTINUED)

RUN 23

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	14.996	230.0	1.037	0.210	0.072
2	14.996	230.0	1.024	0.191	0.092
3	14.996	230.0	1.080	0.206	0.066
4	14.996	230.0	1.122	0.190	0.006
5	14.996	50.0	1.024	-0.240	-0.096
6	14.996	50.0	1.046	-0.214	-0.098
7	14.996	50.0	1.048	-0.199	-0.131
8	14.996	50.0	1.078	-0.193	-0.142
9	14.996	320.0	0.964	0.181	-0.205
10	14.996	320.0	0.995	0.181	-0.207
11	14.996	320.0	1.033	0.178	0.141
12	14.996	140.0	0.890	-0.204	0.072
13	14.996	140.0	1.000	-0.153	0.057
14	14.996	140.0	1.028	-0.173	0.083
15	14.996	140.0	1.030	-0.148	0.101
16	14.996	140.0	1.033	-0.144	0.072
17	14.996	140.0	1.068	-0.158	0.091
18	14.996	20.0	0.853	-0.168	-0.226
19	14.996	20.0	1.004	-0.202	-0.234
20	14.996	20.0	1.039	-0.188	-0.218
21	14.996	200.0	0.000	0.000	0.000
22	14.996	200.0	1.043	-0.102	0.160
23	14.996	200.0	0.997	0.162	0.104
24	14.996	200.0	1.099	0.171	0.097
25	14.996	200.0	1.072	0.170	0.099
26	14.996	200.0	1.116	0.152	0.095

TABLE B-1 (CONTINUED)

RUN 24

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.961	250.0	0.992	0.333	-0.004
2	15.961	250.0	1.030	0.265	-0.018
3	15.961	250.0	1.087	0.275	-0.029
4	15.961	250.0	1.017	0.243	-0.016
5	15.961	70.0	0.984	-0.272	-0.042
6	15.961	70.0	1.010	-0.227	-0.042
7	15.961	70.0	0.982	-0.205	-0.037
8	15.961	70.0	1.028	-0.176	-0.021
9	15.961	340.0	0.821	-0.060	-0.090
10	15.961	340.0	0.920	0.058	-0.140
11	15.961	340.0	0.922	0.184	0.061
12	15.961	160.0	0.938	-0.028	0.128
13	15.961	160.0	0.964	-0.014	0.141
14	15.961	160.0	0.920	0.011	0.177
15	15.961	160.0	0.977	0.008	0.175
16	15.961	160.0	0.970	0.039	0.169
17	15.961	160.0	1.008	0.038	0.157
18	15.961	0.0	0.921	0.062	-0.127
19	15.961	0.0	0.910	-0.048	-0.148
20	15.961	0.0	0.783	-0.115	-0.252
21	15.961	180.0	0.000	0.000	0.000
22	15.961	180.0	1.015	-0.124	-0.004
23	15.961	180.0	0.887	-0.076	0.170
24	15.961	180.0	1.059	0.003	0.132
25	15.961	180.0	1.005	-0.048	0.131
26	15.961	180.0	1.018	-0.059	0.133

TABLE B-1 (CONTINUED)

RUN 27

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.105	10.0	0.721	0.020	-0.056
2	15.105	10.0	0.808	-0.023	-0.089
3	15.105	10.0	1.065	-0.067	-0.175
4	15.105	10.0	0.964	-0.141	-0.189
5	15.105	190.0	1.022	0.122	0.076
6	15.105	190.0	0.974	0.068	0.131
7	15.105	190.0	0.971	0.092	0.114
8	15.105	190.0	1.135	0.027	0.119
9	15.105	100.0	0.986	-0.172	-0.005
10	15.105	100.0	0.895	-0.206	0.023
11	15.105	100.0	0.991	-0.004	-0.204
12	15.105	280.0	0.988	0.197	-0.111
13	15.105	280.0	1.016	0.229	-0.095
14	15.105	280.0	1.049	0.171	-0.077
15	15.105	280.0	1.063	0.208	-0.089
16	15.105	280.0	1.045	0.165	-0.065
17	15.105	280.0	1.029	0.232	-0.047
18	15.105	0.0	0.701	0.052	-0.092
19	15.105	0.0	0.861	-0.081	-0.176
20	15.105	0.0	0.985	-0.053	-0.198
21	15.105	180.0	0.579	0.002	0.191
22	15.105	180.0	0.902	-0.133	0.063
23	15.105	180.0	1.009	0.024	0.093
24	15.105	180.0	1.074	0.048	0.132
25	15.105	180.0	1.055	-0.009	0.133
26	15.105	180.0	0.959	0.014	0.174

TABLE B-1 (CONTINUED)

RUN 28

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.345	350.0	0.850	0.006	0.027
2	15.345	350.0	0.847	0.037	-0.025
3	15.345	350.0	1.084	0.011	-0.117
4	15.345	350.0	1.033	-0.031	-0.122
5	15.345	170.0	1.019	0.016	0.098
6	15.345	170.0	0.902	-0.009	0.166
7	15.345	170.0	1.088	-0.012	0.090
8	15.345	170.0	1.038	-0.042	0.146
9	15.345	80.0	0.998	-0.183	-0.079
10	15.345	80.0	0.878	-0.222	-0.030
11	15.345	80.0	1.008	-0.055	-0.216
12	15.345	260.0	0.991	0.207	-0.030
13	15.345	260.0	1.047	0.235	-0.008
14	15.345	260.0	1.031	0.181	0.001
15	15.345	260.0	1.035	0.225	-0.029
16	15.345	260.0	1.048	0.177	-0.003
17	15.345	260.0	1.040	0.229	-0.012
18	15.345	340.0	0.769	0.104	-0.188
19	15.345	340.0	0.960	0.071	-0.209
20	15.345	340.0	0.987	0.074	-0.192
21	15.345	160.0	0.508	-0.129	0.224
22	15.345	160.0	0.888	-0.124	-0.023
23	15.345	160.0	1.049	-0.040	0.068
24	15.345	160.0	1.032	-0.017	0.139
25	15.345	160.0	1.058	-0.076	0.139
26	15.345	160.0	0.918	-0.059	0.194

TABLE B-1 (CONTINUED)

RUN 29

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.553	330.0	0.756	0.150	-0.006
2	15.553	330.0	0.759	0.084	-0.336
3	15.553	330.0	1.118	0.036	-0.208
4	15.553	330.0	1.028	0.030	-0.200
5	15.553	150.0	1.038	-0.072	0.096
6	15.553	150.0	0.922	-0.096	0.152
7	15.553	150.0	1.062	-0.099	0.079
8	15.553	150.0	1.060	-0.114	0.120
9	15.553	60.0	0.997	-0.161	-0.124
10	15.553	60.0	0.898	-0.211	-0.094
11	15.553	60.0	1.018	-0.090	-0.196
12	15.553	240.0	0.984	0.184	-0.002
13	15.553	240.0	1.029	0.216	0.015
14	15.553	240.0	1.043	0.168	0.029
15	15.553	240.0	1.087	0.169	0.010
16	15.553	240.0	0.973	0.184	0.056
17	15.553	240.0	1.036	0.188	0.038
18	15.553	320.0	0.895	0.165	-0.179
19	15.553	320.0	1.049	0.142	-0.216
20	15.553	320.0	0.995	0.149	-0.214
21	15.553	140.0	0.000	0.000	0.000
22	15.553	140.0	0.939	-0.099	-0.078
23	15.553	140.0	0.963	-0.144	0.063
24	15.553	140.0	1.055	-0.082	0.101
25	15.553	140.0	1.026	-0.139	0.096
26	15.553	140.0	0.944	-0.140	0.133

TABLE B-1 (CONTINUED)

RUN 30

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	14.451	290.0	0.916	0.268	-0.046
2	14.451	290.0	0.983	0.247	-0.125
3	14.451	290.0	1.113	0.162	-0.132
4	14.451	290.0	1.092	0.160	-0.130
5	14.451	110.0	1.047	-0.193	0.040
6	14.451	110.0	0.954	-0.217	0.095
7	14.451	110.0	1.075	-0.212	0.018
8	14.451	110.0	0.995	-0.217	0.079
9	14.451	20.0	1.025	-0.094	-0.212
10	14.451	20.0	0.888	-0.153	-0.176
11	14.451	20.0	0.994	-0.181	-0.161
12	14.451	200.0	1.009	0.080	0.098
13	14.451	200.0	1.036	0.141	0.107
14	14.451	200.0	1.056	0.079	0.109
15	14.451	200.0	1.062	0.123	0.103
16	14.451	200.0	1.052	0.090	0.127
17	14.451	200.0	1.053	0.139	0.123
18	14.451	300.0	0.922	0.206	-0.130
19	14.451	300.0	1.060	0.214	-0.166
20	14.451	300.0	1.035	0.217	-0.175
21	14.451	120.0	0.000	0.000	0.000
22	14.451	120.0	0.910	-0.036	-0.174
23	14.451	120.0	1.005	-0.210	-0.006
24	14.451	120.0	1.020	-0.115	0.057
25	14.451	120.0	1.057	-0.189	0.047
26	14.451	120.0	0.927	-0.218	0.099

TABLE B-1 (CONTINUED)

RUN 32

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	14.994	250.0	1.266	0.038	0.006
2	14.994	250.0	0.920	0.261	0.023
3	14.994	250.0	1.090	0.198	0.003
4	14.994	250.0	0.000	0.000	0.000
5	14.994	70.0	1.034	-0.232	-0.050
6	14.994	70.0	0.957	-0.288	-0.015
7	14.994	70.0	0.643	-0.359	-0.026
8	14.994	70.0	1.163	-0.198	-0.105
9	14.994	340.0	0.927	-0.012	-0.197
10	14.994	340.0	0.768	0.034	-0.137
11	14.994	340.0	0.000	0.000	0.000
12	14.994	160.0	1.025	-0.071	0.038
13	14.994	160.0	0.913	0.157	0.137
14	14.994	160.0	1.047	-0.047	0.121
15	14.994	160.0	0.000	0.000	0.000
16	14.994	160.0	1.087	-0.076	0.068
17	14.994	160.0	1.174	-0.154	0.130
18	14.994	290.0	0.899	0.269	-0.119
19	14.994	290.0	0.920	0.309	0.005
20	14.994	290.0	0.000	0.000	0.000
21	14.994	110.0	0.488	-0.205	-0.042
22	14.994	110.0	0.000	0.000	0.000
23	14.994	110.0	0.000	0.000	0.000
24	14.994	110.0	0.864	-0.173	0.181
25	14.994	110.0	1.202	-0.041	0.063
26	14.994	110.0	0.742	-0.190	0.084

TABLE B-1 (CONTINUED)

RUN 33

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	15.166	230.0	1.065	0.309	0.039
2	15.166	230.0	0.940	0.256	0.069
3	15.166	230.0	1.208	0.196	0.004
4	15.166	230.0	1.036	0.205	0.016
5	15.166	50.0	1.015	-0.220	-0.096
6	15.166	50.0	0.951	-0.263	-0.054
7	15.166	50.0	1.072	-0.222	-0.117
8	15.166	50.0	1.076	-0.217	-0.112
9	15.166	320.0	0.957	0.145	-0.219
10	15.166	320.0	0.872	0.148	-0.185
11	15.166	320.0	0.967	0.185	0.071
12	15.166	140.0	0.996	-0.143	0.104
13	15.166	140.0	1.064	-0.021	0.134
14	15.166	140.0	1.071	-0.080	0.100
15	15.166	140.0	1.015	-0.072	0.113
16	15.166	140.0	1.064	-0.092	0.139
17	15.166	140.0	1.069	-0.055	0.151
18	15.166	280.0	0.916	0.298	-0.071
19	15.166	280.0	1.031	0.231	-0.111
20	15.166	280.0	1.079	0.240	-0.095
21	15.166	100.0	0.000	0.000	0.000
22	15.166	100.0	0.939	0.030	-0.199
23	15.166	100.0	1.005	-0.233	-0.060
24	15.166	100.0	0.969	-0.168	0.013
25	15.166	100.0	1.038	-0.210	-0.012
26	15.166	100.0	0.905	-0.244	0.079

TABLE B-1 (CONTINUED)

RUN 34

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.154	10.0	0.608	-0.059	-0.087
2	25.154	10.0	0.905	-0.041	-0.118
3	25.154	10.0	0.930	-0.083	-0.228
4	25.154	10.0	1.031	-0.123	-0.188
5	25.154	190.0	1.045	0.110	0.094
6	25.154	190.0	0.999	0.090	0.132
7	25.154	190.0	1.008	0.072	0.116
8	25.154	190.0	1.015	0.055	0.133
9	25.154	100.0	0.987	-0.190	0.005
10	25.154	100.0	0.952	-0.188	0.008
11	25.154	100.0	1.018	-0.001	-0.195
12	25.154	280.0	0.992	0.224	-0.115
13	25.154	280.0	1.023	0.221	-0.096
14	25.154	280.0	1.002	0.191	-0.081
15	25.154	280.0	1.052	0.216	-0.083
16	25.154	280.0	1.022	0.195	-0.063
17	25.154	280.0	1.008	0.212	-0.048
18	25.154	100.0	0.946	-0.203	-0.005
19	25.154	100.0	1.022	-0.205	-0.000
20	25.154	100.0	1.016	-0.184	0.012
21	25.154	280.0	0.000	0.000	0.000
22	25.154	280.0	0.982	0.134	0.238
23	25.154	280.0	1.038	0.222	-0.149
24	25.154	280.0	1.079	0.233	-0.101
25	25.154	280.0	1.041	0.209	-0.119
26	25.154	280.0	0.992	0.209	-0.110

TABLE B-1 (CONTINUED)

RUN 35

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.224	350.0	0.751	0.002	0.006
2	25.224	350.0	0.919	0.015	-0.053
3	25.224	350.0	1.064	0.021	-0.096
4	25.224	350.0	0.948	-0.034	-0.162
5	25.224	170.0	1.017	0.021	0.093
6	25.224	170.0	0.993	0.007	0.133
7	25.224	170.0	1.053	-0.004	0.125
8	25.224	170.0	1.067	-0.022	0.137
9	25.224	80.0	1.020	-0.208	-0.075
10	25.224	80.0	0.985	-0.212	-0.043
11	25.224	80.0	1.029	-0.052	-0.206
12	25.224	260.0	1.009	0.234	-0.047
13	25.224	260.0	1.033	0.236	-0.030
14	25.224	260.0	1.016	0.197	-0.006
15	25.224	260.0	1.059	0.227	-0.019
16	25.224	260.0	1.043	0.212	-0.015
17	25.224	260.0	1.059	0.222	-0.014
18	25.224	80.0	0.966	-0.243	-0.084
19	25.224	80.0	1.032	-0.229	-0.074
20	25.224	80.0	1.045	-0.204	-0.053
21	25.224	260.0	0.000	0.000	0.000
22	25.224	260.0	0.977	0.059	0.258
23	25.224	260.0	1.038	0.243	-0.057
24	25.224	260.0	1.071	0.263	-0.002
25	25.224	260.0	1.063	0.227	-0.036
26	25.224	260.0	1.030	0.238	-0.020

TABLE B-1 (CONTINUED)

RUN 36

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.786	330.0	0.792	0.067	-0.015
2	25.786	330.0	0.865	0.053	-0.155
3	25.786	330.0	1.049	0.054	-0.209
4	25.786	330.0	1.052	0.044	-0.197
5	25.786	150.0	1.015	-0.074	0.090
6	25.786	150.0	1.000	-0.103	0.120
7	25.786	150.0	1.032	-0.089	0.111
8	25.786	150.0	1.051	-0.088	0.123
9	25.786	60.0	1.012	-0.190	-0.129
10	25.786	60.0	0.977	-0.198	-0.103
11	25.786	60.0	1.022	-0.106	-0.199
12	25.786	240.0	1.011	0.213	0.008
13	25.786	240.0	1.046	0.217	0.021
14	25.786	240.0	1.027	0.176	0.025
15	25.786	240.0	1.055	0.203	0.049
16	25.786	240.0	1.057	0.187	0.059
17	25.786	240.0	1.052	0.199	0.058
18	25.786	60.0	0.959	-0.249	-0.146
19	25.786	60.0	1.021	-0.238	-0.138
20	25.786	60.0	1.029	-0.211	-0.101
21	25.786	240.0	0.000	0.000	0.000
22	25.786	240.0	0.980	0.009	0.247
23	25.786	240.0	1.038	0.227	-0.014
24	25.786	240.0	1.071	0.236	0.036
25	25.786	240.0	1.055	0.200	0.038
26	25.786	240.0	1.029	0.204	0.055

TABLE B-1 (CONTINUED)

RUN 37

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	24.791	310.0	0.767	0.205	-0.013
2	24.791	310.0	1.275	0.137	-0.251
3	24.791	310.0	0.465	-0.015	-0.206
4	24.791	310.0	0.967	0.339	-0.185
5	24.791	130.0	0.925	-0.313	0.080
6	24.791	130.0	1.200	-0.121	-0.017
7	24.791	130.0	0.942	-0.129	0.248
8	24.791	130.0	0.940	0.001	0.107
9	24.791	40.0	1.004	-0.171	-0.167
10	24.791	40.0	0.964	-0.174	-0.167
11	24.791	40.0	0.999	-0.146	-0.175
12	24.791	220.0	0.970	0.207	0.044
13	24.791	220.0	1.010	0.176	0.061
14	24.791	220.0	0.948	0.178	0.063
15	24.791	220.0	0.986	0.180	0.147
16	24.791	220.0	0.966	0.276	0.084
17	24.791	220.0	0.964	0.110	0.088
18	24.791	40.0	1.318	-0.151	-0.184
19	24.791	40.0	0.988	-0.216	-0.200
20	24.791	40.0	1.007	-0.216	-0.178
21	24.791	220.0	0.000	0.000	0.000
22	24.791	220.0	0.997	-0.074	0.178
23	24.791	220.0	1.020	0.173	0.061
24	24.791	220.0	1.047	0.179	0.096
25	24.791	220.0	1.036	0.165	0.094
26	24.791	220.0	1.041	0.142	0.094

TABLE B-1 (CONTINUED)

RUN 38

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.927	290.0	0.859	0.612	-0.018
2	25.927	290.0	1.035	0.228	-0.136
3	25.927	290.0	1.042	0.195	-0.147
4	25.927	290.0	1.046	0.186	-0.144
5	25.927	110.0	1.023	-0.209	0.039
6	25.927	110.0	1.004	-0.211	0.066
7	25.927	110.0	1.058	-0.200	0.042
8	25.927	110.0	1.082	-0.205	0.045
9	25.927	20.0	0.920	-0.080	-0.224
10	25.927	20.0	0.960	-0.149	-0.204
11	25.927	20.0	1.014	-0.191	-0.153
12	25.927	200.0	1.001	0.106	0.091
13	25.927	200.0	1.020	0.112	0.111
14	25.927	200.0	1.008	0.077	0.112
15	25.927	200.0	1.031	0.109	0.123
16	25.927	200.0	1.036	0.092	0.134
17	25.927	200.0	1.051	0.106	0.134
18	25.927	20.0	0.773	-0.147	-0.195
19	25.927	20.0	0.994	-0.192	-0.239
20	25.927	20.0	1.048	-0.158	-0.223
21	25.927	200.0	0.000	0.000	0.000
22	25.927	200.0	0.987	-0.108	0.134
23	25.927	200.0	1.036	0.121	0.085
24	25.927	200.0	1.063	0.126	0.130
25	25.927	200.0	1.061	0.083	0.121
26	25.927	200.0	1.029	0.090	0.141

TABLE B-1 (CONTINUED)

RUN 39

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.330	270.0	1.053	0.315	-0.001
2	25.330	270.0	1.050	0.272	-0.060
3	25.330	270.0	1.085	0.237	-0.073
4	25.330	270.0	1.070	0.232	-0.083
5	25.330	90.0	1.035	-0.251	0.002
6	25.330	90.0	0.984	-0.252	0.012
7	25.330	90.0	1.065	-0.233	-0.009
8	25.330	90.0	1.053	-0.207	-0.003
9	25.330	0.0	0.853	0.041	-0.071
10	25.330	0.0	0.838	-0.065	-0.140
11	25.330	0.0	0.907	-0.199	-0.095
12	25.330	180.0	0.984	0.028	0.113
13	25.330	180.0	1.016	0.046	0.128
14	25.330	180.0	1.023	0.011	0.130
15	25.330	180.0	1.034	0.032	0.138
16	25.330	180.0	1.037	0.021	0.160
17	25.330	180.0	1.057	0.041	0.152
18	25.330	0.0	0.764	0.039	-0.157
19	25.330	0.0	0.886	-0.054	-0.157
20	25.330	0.0	0.996	-0.082	-0.199
21	25.330	180.0	0.000	0.000	0.000
22	25.330	180.0	0.961	-0.126	0.018
23	25.330	180.0	1.052	0.009	0.104
24	25.330	180.0	1.061	0.017	0.155
25	25.330	180.0	1.067	-0.004	0.142
26	25.330	180.0	1.020	0.001	0.166

TABLE B-1 (CONTINUED)

RUN 40

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	26.061	250.0	1.054	0.327	0.015
2	26.061	250.0	1.029	0.281	0.003
3	26.061	250.0	1.119	0.242	0.023
4	26.061	250.0	1.096	0.231	0.009
5	26.061	70.0	1.027	-0.255	-0.041
6	26.061	70.0	1.004	-0.246	-0.032
7	26.061	70.0	1.041	-0.223	-0.057
8	26.061	70.0	1.031	-0.211	-0.047
9	26.061	340.0	0.823	0.055	-0.101
10	26.061	340.0	0.913	0.086	-0.143
11	26.061	340.0	0.894	-0.198	0.041
12	26.061	160.0	0.989	-0.036	0.111
13	26.061	160.0	1.030	-0.025	0.127
14	26.061	160.0	1.026	-0.045	0.128
15	26.061	160.0	1.045	-0.037	0.137
16	26.061	160.0	1.040	-0.043	0.156
17	26.061	160.0	1.033	-0.032	0.154
18	26.061	340.0	0.891	0.098	-0.169
19	26.061	340.0	0.950	0.074	-0.192
20	26.061	340.0	0.890	0.087	-0.217
21	26.061	160.0	0.000	0.000	0.000
22	26.061	160.0	0.985	-0.115	-0.050
23	26.061	160.0	1.053	-0.060	0.102
24	26.061	160.0	1.081	-0.018	0.151
25	26.061	160.0	1.100	-0.061	0.135
26	26.061	160.0	1.065	-0.076	0.144

TABLE B-1 (CONTINUED)

RUN 47

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.080	230.0	1.028	0.275	0.051
2	25.080	230.0	1.038	0.243	0.038
3	25.080	230.0	1.027	0.244	0.032
4	25.080	230.0	1.068	0.225	0.016
5	25.080	50.0	1.004	-0.264	-0.088
6	25.080	50.0	1.025	-0.223	-0.101
7	25.080	50.0	1.017	-0.210	-0.102
8	25.080	50.0	1.010	-0.200	-0.119
9	25.080	320.0	0.973	0.152	-0.222
10	25.080	320.0	0.999	0.137	-0.199
11	25.080	320.0	0.981	0.175	0.110
12	25.080	140.0	0.944	-0.107	0.096
13	25.080	140.0	1.004	-0.106	0.105
14	25.080	140.0	0.968	-0.098	0.112
15	25.080	140.0	1.018	-0.075	0.129
16	25.080	140.0	0.968	-0.094	0.142
17	25.080	140.0	1.011	-0.092	0.132
18	25.080	320.0	0.986	0.183	-0.194
19	25.080	320.0	1.021	0.159	-0.185
20	25.080	320.0	1.012	0.152	-0.199
21	25.080	140.0	0.000	0.000	0.000
22	25.080	140.0	1.003	-0.065	-0.150
23	25.080	140.0	0.992	-0.153	0.068
24	25.080	140.0	1.008	-0.123	0.093
25	25.080	140.0	1.033	-0.133	0.085
26	25.080	140.0	1.036	-0.156	0.079

TABLE B-1 (CONTINUED)

RUN 48

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.523	210.0	1.013	0.187	0.073
2	25.523	210.0	1.025	0.159	0.099
3	25.523	210.0	0.836	0.422	0.102
4	25.523	210.0	1.080	0.365	-0.059
5	25.523	30.0	0.913	-0.221	-0.137
6	25.523	30.0	0.000	0.000	0.000
7	25.523	30.0	0.910	-0.023	-0.134
8	25.523	30.0	1.049	-0.046	-0.149
9	25.523	300.0	0.973	0.190	-0.180
10	25.523	300.0	0.994	0.197	-0.159
11	25.523	300.0	0.984	0.154	0.193
12	25.523	120.0	0.962	-0.174	0.044
13	25.523	120.0	1.000	-0.182	0.057
14	25.523	120.0	0.815	-0.173	-0.226
15	25.523	120.0	0.955	-0.171	0.156
16	25.523	120.0	0.989	-0.190	0.085
17	25.523	120.0	1.002	-0.136	0.079
18	25.523	300.0	0.989	0.237	-0.147
19	25.523	300.0	1.007	0.203	-0.138
20	25.523	300.0	1.037	0.201	-0.149
21	25.523	120.0	0.000	0.000	0.000
22	25.523	120.0	1.000	-0.015	-0.203
23	25.523	120.0	0.997	-0.192	0.018
24	25.523	120.0	1.240	-0.136	0.037
25	25.523	120.0	1.026	-0.168	0.040
26	25.523	120.0	1.040	-0.193	0.036

TABLE B-1 (CONTINUED)

RUN 49

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	24.737	210.0	1.019	0.170	0.080
2	24.737	210.0	1.006	0.143	0.100
3	24.737	210.0	0.990	0.144	0.115
4	24.737	210.0	1.185	0.132	-0.082
5	24.737	30.0	0.896	-0.207	-0.147
6	24.737	30.0	0.000	0.000	0.000
7	24.737	30.0	0.964	-0.028	-0.126
8	24.737	30.0	1.056	-0.050	-0.171
9	24.737	300.0	0.967	0.205	-0.164
10	24.737	300.0	0.972	0.197	-0.152
11	24.737	300.0	0.982	0.140	0.183
12	24.737	120.0	0.956	-0.189	0.026
13	24.737	120.0	0.999	-0.182	0.039
14	24.737	120.0	0.968	-0.192	0.044
15	24.737	120.0	0.979	-0.153	0.062
16	24.737	120.0	1.007	-0.166	0.055
17	24.737	120.0	1.017	-0.154	0.055
18	24.737	300.0	0.982	0.218	-0.151
19	24.737	300.0	1.002	0.193	-0.157
20	24.737	300.0	1.044	0.188	-0.161
21	24.737	120.0	0.000	0.000	0.000
22	24.737	120.0	0.975	-0.040	-0.192
23	24.737	120.0	0.994	-0.185	0.038
24	24.737	120.0	0.987	-0.170	0.071
25	24.737	120.0	0.997	-0.156	0.068
26	24.737	120.0	1.021	-0.153	0.076

TABLE B-1 (CONTINUED)

RUN 50

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.980	190.0	1.012	0.096	0.096
2	25.980	190.0	1.041	0.068	0.120
3	25.980	190.0	1.037	0.071	0.131
4	25.980	190.0	1.303	0.071	-0.227
5	25.980	10.0	0.879	-0.049	-0.090
6	25.980	10.0	0.916	-0.025	-0.107
7	25.980	10.0	0.970	-0.046	-0.137
8	25.980	10.0	1.024	-0.102	-0.170
9	25.980	280.0	0.982	0.233	-0.110
10	25.980	280.0	0.986	0.226	-0.096
11	25.980	280.0	1.076	0.087	0.194
12	25.980	100.0	0.976	-0.228	-0.019
13	25.980	100.0	0.998	-0.226	-0.002
14	25.980	100.0	0.970	-0.216	-0.010
15	25.980	100.0	1.096	-0.167	-0.005
16	25.980	100.0	0.998	-0.204	0.008
17	25.980	100.0	1.027	-0.187	0.003
18	25.980	280.0	0.985	0.262	-0.091
19	25.980	280.0	1.017	0.228	-0.088
20	25.980	280.0	1.048	0.227	-0.087
21	25.980	100.0	0.000	0.000	0.000
22	25.980	100.0	0.990	0.035	-0.231
23	25.980	100.0	1.001	-0.222	-0.003
24	25.980	100.0	1.000	-0.213	-0.008
25	25.980	100.0	1.008	-0.203	-0.002
26	25.980	100.0	1.031	-0.200	0.005

TABLE B-1 (CONTINUED)

RUN 51

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	26.065	170.0	1.020	-0.008	0.103
2	26.065	170.0	1.039	0.000	0.120
3	26.065	170.0	1.048	-0.007	0.131
4	26.065	170.0	1.354	-0.008	-0.285
5	26.065	350.0	0.794	-0.029	-0.057
6	26.065	350.0	0.911	0.033	-0.075
7	26.065	350.0	0.938	0.044	-0.141
8	26.065	350.0	0.961	0.011	-0.164
9	26.065	260.0	0.972	0.237	-0.041
10	26.065	260.0	0.990	0.225	-0.019
11	26.065	260.0	1.010	0.027	0.210
12	26.065	80.0	0.961	-0.226	-0.079
13	26.065	80.0	0.992	-0.230	-0.067
14	26.065	80.0	0.965	-0.220	-0.036
15	26.065	80.0	0.870	-0.187	-0.282
16	26.065	80.0	0.961	-0.201	-0.019
17	26.065	80.0	1.019	-0.189	-0.052
18	26.065	260.0	0.986	0.258	-0.019
19	26.065	260.0	1.007	0.224	-0.008
20	26.065	260.0	1.019	0.224	-0.016
21	26.065	80.0	0.000	0.000	0.000
22	26.065	80.0	0.978	0.100	-0.235
23	26.065	80.0	0.987	-0.227	-0.090
24	26.065	80.0	0.982	-0.205	-0.053
25	26.065	80.0	0.988	-0.200	-0.071
26	26.065	80.0	1.012	-0.200	-0.059

TABLE B-1 (CONTINUED)

RUN 52

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	24.306	150.0	0.919	-0.012	0.078
2	24.306	150.0	1.021	-0.081	0.107
3	24.306	150.0	1.020	-0.088	0.120
4	24.306	150.0	1.231	-0.101	-0.111
5	24.306	330.0	0.725	0.313	-0.155
6	24.306	330.0	1.007	0.010	-0.188
7	24.306	330.0	1.019	0.061	-0.200
8	24.306	330.0	0.952	0.066	-0.201
9	24.306	240.0	0.965	0.216	0.002
10	24.306	240.0	0.912	0.158	0.027
11	24.306	240.0	1.008	0.028	0.189
12	24.306	60.0	0.977	-0.211	-0.133
13	24.306	60.0	0.983	-0.207	-0.123
14	24.306	60.0	0.962	-0.211	-0.106
15	24.306	60.0	0.981	-0.179	-0.111
16	24.306	60.0	0.976	-0.184	-0.095
17	24.306	60.0	0.986	-0.164	-0.100
18	24.306	240.0	0.955	0.223	0.020
19	24.306	240.0	0.991	0.189	0.036
20	24.306	240.0	1.018	0.190	0.044
21	24.306	60.0	0.000	0.000	0.000
22	24.306	60.0	0.975	0.175	-0.216
23	24.306	60.0	0.969	-0.221	-0.174
24	24.306	60.0	1.016	-0.179	-0.110
25	24.306	60.0	0.993	-0.187	-0.127
26	24.306	60.0	0.979	-0.183	-0.132

TABLE B-1 (CONTINUED)

RUN 53

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.175	140.0	0.990	-0.117	0.062
2	25.175	140.0	1.005	-0.094	0.099
3	25.175	140.0	1.008	-0.099	0.108
4	25.175	140.0	1.180	-0.116	-0.080
5	25.175	320.0	0.997	0.175	-0.158
6	25.175	320.0	1.000	0.144	-0.170
7	25.175	320.0	0.987	0.135	-0.199
8	25.175	320.0	0.975	0.108	-0.205
9	25.175	230.0	0.969	0.205	0.021
10	25.175	230.0	0.978	0.195	0.042
11	25.175	230.0	0.987	0.043	0.189
12	25.175	50.0	0.969	-0.198	-0.151
13	25.175	50.0	1.005	-0.197	-0.146
14	25.175	50.0	0.978	-0.202	-0.131
15	25.175	50.0	0.990	-0.167	-0.122
16	25.175	50.0	0.980	-0.170	-0.134
17	25.175	50.0	0.917	-0.146	-0.152
18	25.175	230.0	0.965	0.197	0.047
19	25.175	230.0	0.997	0.168	0.061
20	25.175	230.0	1.020	0.173	0.066
21	25.175	50.0	0.000	0.000	0.000
22	25.175	50.0	0.980	0.206	-0.207
23	25.175	50.0	0.993	-0.196	-0.204
24	25.175	50.0	1.012	-0.174	-0.151
25	25.175	50.0	0.968	-0.173	-0.139
26	25.175	50.0	0.987	-0.168	-0.129

TABLE B-1 (CONTINUED)

RUN 56

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.905	160.0	1.043	0.036	0.111
2	25.905	160.0	1.060	0.004	0.133
3	25.905	160.0	1.068	-0.008	0.146
4	25.905	160.0	0.000	0.000	0.000
5	25.905	340.0	0.855	0.032	-0.021
6	25.905	340.0	0.935	-0.040	-0.108
7	25.905	340.0	1.069	0.005	-0.121
8	25.905	340.0	1.040	0.030	-0.186
9	25.905	250.0	0.997	0.250	-0.051
10	25.905	250.0	1.013	0.235	0.005
11	25.905	250.0	1.021	0.010	0.219
12	25.905	70.0	0.989	-0.248	-0.102
13	25.905	70.0	1.024	-0.233	-0.069
14	25.905	70.0	1.000	-0.222	-0.044
15	25.905	70.0	1.060	-0.199	-0.063
16	25.905	70.0	1.069	-0.203	-0.062
17	25.905	70.0	1.080	-0.188	-0.072
18	25.905	250.0	1.009	0.252	0.017
19	25.905	250.0	1.024	0.215	0.027
20	25.905	250.0	1.044	0.211	0.047
21	25.905	70.0	0.000	0.000	0.000
22	25.905	70.0	1.005	0.166	-0.235
23	25.905	70.0	1.004	-0.229	-0.142
24	25.905	70.0	1.042	-0.202	-0.081
25	25.905	70.0	1.049	-0.203	-0.114
26	25.905	70.0	1.028	-0.198	-0.091

TABLE B-1 (CONTINUED)

RUN 57

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	24.883	180.0	1.066	0.075	0.115
2	24.883	180.0	1.078	0.053	0.128
3	24.883	180.0	1.080	0.047	0.141
4	24.883	180.0	1.356	0.054	-0.233
5	24.883	0.0	0.866	-0.026	-0.075
6	24.883	0.0	0.981	-0.024	-0.073
7	24.883	0.0	0.972	-0.042	-0.134
8	24.883	0.0	1.051	-0.091	-0.173
9	24.883	270.0	1.015	0.250	-0.106
10	24.883	270.0	1.036	0.238	-0.078
11	24.883	270.0	1.047	0.079	0.220
12	24.883	90.0	0.991	-0.242	-0.029
13	24.883	90.0	1.028	-0.224	-0.011
14	24.883	90.0	1.007	-0.227	0.011
15	24.883	90.0	0.998	-0.194	0.001
16	24.883	90.0	0.984	-0.205	-0.005
17	24.883	90.0	1.034	-0.183	-0.002
18	24.883	270.0	1.002	0.269	-0.047
19	24.883	270.0	1.034	0.240	-0.022
20	24.883	270.0	1.058	0.239	-0.026
21	24.883	90.0	0.000	0.000	0.000
22	24.883	90.0	1.017	0.075	-0.242
23	24.883	90.0	1.027	-0.236	-0.060
24	24.883	90.0	1.033	-0.214	-0.020
25	24.883	90.0	1.028	-0.203	-0.031
26	24.883	90.0	1.056	-0.208	-0.040

TABLE B-1 (CONTINUED)

RUN 58

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.405	220.0	1.047	0.258	0.066
2	25.405	220.0	1.032	0.243	0.066
3	25.405	220.0	1.059	0.218	0.057
4	25.405	220.0	1.287	0.213	-0.201
5	25.405	40.0	0.997	-0.243	-0.103
6	25.405	40.0	1.021	-0.214	-0.122
7	25.405	40.0	1.039	-0.206	-0.134
8	25.405	40.0	1.026	-0.196	-0.149
9	25.405	310.0	0.990	0.163	-0.220
10	25.405	310.0	1.005	0.155	-0.199
11	25.405	310.0	0.996	0.190	0.151
12	25.405	130.0	1.015	-0.121	0.073
13	25.405	130.0	1.023	-0.136	0.091
14	25.405	130.0	0.995	-0.138	0.104
15	25.405	130.0	1.027	-0.119	0.115
16	25.405	130.0	1.010	-0.122	0.126
17	25.405	130.0	0.981	-0.058	0.131
18	25.405	310.0	1.004	0.226	-0.167
19	25.405	310.0	1.038	0.198	-0.175
20	25.405	310.0	0.946	0.195	-0.083
21	25.405	130.0	0.000	0.000	0.000
22	25.405	130.0	1.012	-0.032	-0.193
23	25.405	130.0	0.970	-0.189	-0.021
24	25.405	130.0	1.005	-0.171	0.067
25	25.405	130.0	1.042	-0.165	0.069
26	25.405	130.0	1.042	-0.167	0.078

TABLE B-1 (CONTINUED)

RUN 59

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.340	260.0	1.057	0.325	-0.009
2	25.340	260.0	1.078	0.277	-0.033
3	25.340	260.0	1.087	0.266	-0.029
4	25.340	260.0	1.076	0.249	-0.039
5	25.340	80.0	1.019	-0.274	-0.028
6	25.340	80.0	1.043	-0.238	-0.030
7	25.340	80.0	1.036	-0.237	-0.031
8	25.340	80.0	1.022	-0.201	-0.023
9	25.340	350.0	0.879	0.031	-0.052
10	25.340	350.0	0.927	0.044	-0.124
11	25.340	350.0	0.851	0.174	-0.004
12	25.340	170.0	0.973	0.003	0.112
13	25.340	170.0	1.038	-0.001	0.133
14	25.340	170.0	1.009	-0.000	0.153
15	25.340	170.0	1.039	0.012	0.152
16	25.340	170.0	1.028	0.007	0.163
17	25.340	170.0	1.053	0.013	0.160
18	25.340	350.0	0.849	0.058	-0.195
19	25.340	350.0	0.922	0.017	-0.156
20	25.340	350.0	0.886	0.005	-0.200
21	25.340	170.0	0.000	0.000	0.000
22	25.340	170.0	1.019	-0.114	-0.038
23	25.340	170.0	1.030	-0.041	0.116
24	25.340	170.0	1.036	0.007	0.146
25	25.340	170.0	1.067	-0.020	0.141
26	25.340	170.0	1.060	-0.048	0.144

TABLE B-1 (CONTINUED)

RUN 60

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.387	340.0	0.715	-0.011	-0.007
2	25.387	340.0	0.898	0.024	-0.081
3	25.387	340.0	1.021	0.043	-0.134
4	25.387	340.0	0.883	0.027	-0.090
5	25.387	160.0	1.011	-0.029	0.092
6	25.387	160.0	1.012	-0.043	0.126
7	25.387	160.0	0.995	-0.052	0.136
8	25.387	160.0	0.951	-0.046	0.150
9	25.387	70.0	1.010	-0.214	-0.095
10	25.387	70.0	0.996	-0.192	-0.073
11	25.387	70.0	1.003	-0.077	-0.198
12	25.387	250.0	0.995	0.243	-0.025
13	25.387	250.0	1.034	0.221	0.002
14	25.387	250.0	1.000	0.195	-0.002
15	25.387	250.0	1.035	0.216	0.008
16	25.387	250.0	1.019	0.216	0.012
17	25.387	250.0	1.039	0.210	0.013
18	25.387	70.0	0.982	-0.230	-0.113
19	25.387	70.0	1.023	-0.236	-0.088
20	25.387	70.0	0.837	-0.220	0.122
21	25.387	250.0	0.000	0.000	0.000
22	25.387	250.0	1.020	0.036	0.243
23	25.387	250.0	1.040	0.239	-0.014
24	25.387	250.0	1.069	0.250	-0.005
25	25.387	250.0	1.051	0.229	0.007
26	25.387	250.0	1.024	0.273	-0.005

TABLE B-1 (CONTINUED)

RUN 61

TUBE	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT. VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	23.909	0.0	0.732	-0.044	-0.043
2	23.909	0.0	1.027	-0.024	-0.096
3	23.909	0.0	1.046	-0.028	-0.135
4	23.909	0.0	1.119	-0.125	-0.188
5	23.909	180.0	1.103	0.079	0.102
6	23.909	180.0	1.077	0.067	0.126
7	23.909	180.0	1.089	0.044	0.137
8	23.909	180.0	1.091	0.031	0.141
9	23.909	90.0	1.059	-0.220	-0.033
10	23.909	90.0	1.069	-0.202	-0.013
11	23.909	90.0	1.091	-0.027	-0.212
12	23.909	270.0	1.089	0.264	-0.090
13	23.909	270.0	1.109	0.244	-0.072
14	23.909	270.0	1.066	0.210	-0.052
15	23.909	270.0	1.110	0.237	-0.054
16	23.909	270.0	1.090	0.236	-0.047
17	23.909	270.0	1.068	0.227	-0.040
18	23.909	90.0	1.053	-0.235	-0.048
19	23.909	90.0	1.084	-0.250	-0.020
20	23.909	90.0	1.093	-0.222	0.002
21	23.909	270.0	0.000	0.000	0.000
22	23.909	270.0	1.108	0.104	0.247
23	23.909	270.0	1.089	0.251	-0.155
24	23.909	270.0	1.146	0.269	-0.047
25	23.909	270.0	1.089	0.256	-0.089
26	23.909	270.0	1.092	0.233	-0.081

APPENDIX C

VELOCITY COMPONENT RATIOS FROM EXPERIMENT 2

Units are presented as the original data were recorded.

Speeds are given in feet per second.

Angles are given in degrees.

TABLE C-1 - VELOCITY COMPONENT RATIOS FROM RUNS 62-77

RUN 62	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	26.298	0.0	0.681	-0.030	-0.020
2	26.298	0.0	0.894	0.006	-0.078
3	26.298	0.0	0.950	-0.013	-0.112
4	26.298	0.0	0.971	-0.091	-0.139
5	26.298	180.0	1.224	-0.139	0.090
6	26.298	180.0	1.021	0.055	0.118
7	26.298	180.0	1.015	0.062	0.134
8	26.298	180.0	1.006	0.060	0.128

RUN 63

1	26.273	350.0	0.739	-0.042	-0.001
2	26.273	350.0	0.902	0.014	-0.066
3	26.273	350.0	1.013	0.038	-0.105
4	26.273	350.0	0.916	0.003	-0.152
5	26.273	170.0	1.191	-0.170	0.084
6	26.273	170.0	1.007	-0.002	0.128
7	26.273	170.0	1.026	-0.007	0.140
8	26.273	170.0	1.010	-0.026	0.139

TABLE C-1 (CONTINUED)

RUN 65	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	26.103	340.0	0.644	-0.013	-0.035
2	26.103	340.0	0.880	0.034	-0.121
3	26.103	340.0	0.905	0.040	-0.188
4	26.103	340.0	0.987	0.035	-0.171
5	26.103	160.0	1.164	-0.193	0.095
6	26.103	160.0	1.011	-0.031	0.119
7	26.103	160.0	1.027	-0.043	0.130
8	26.103	160.0	1.035	-0.033	0.132

RUN 66					
1	24.132	300.0	0.839	0.319	-0.077
2	24.132	300.0	1.059	0.219	-0.162
3	24.132	300.0	1.039	0.218	-0.171
4	24.132	300.0	1.069	0.196	-0.169
5	24.132	120.0	1.152	-0.279	0.052
6	24.132	120.0	1.038	-0.187	0.073
7	24.132	120.0	1.045	-0.171	0.078
8	24.132	120.0	1.036	-0.153	0.089

TABLE C-1 (CONTINUED)

RUN 67	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.475	260.0	1.040	0.330	0.007
2	25.475	260.0	1.067	0.274	-0.041
3	25.475	260.0	1.072	0.267	-0.029
4	25.475	260.0	1.079	0.253	-0.047
5	25.475	80.0	1.044	-0.283	-0.026
6	25.475	80.0	1.040	-0.245	-0.022
7	25.475	80.0	1.052	-0.235	-0.028
8	25.475	80.0	1.026	-0.213	-0.022

RUN 68					
1	26.048	220.0	1.020	0.253	0.075
2	26.048	220.0	1.024	0.222	0.073
3	26.048	220.0	1.030	0.209	0.073
4	26.048	220.0	1.115	0.193	-0.007
5	26.048	40.0	1.073	-0.277	-0.113
6	26.048	40.0	1.002	-0.206	-0.125
7	26.048	40.0	1.016	-0.190	-0.136
8	26.048	40.0	1.005	-0.180	-0.136

TABLE C-1 (CONTINUED)

RUN 69	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	26.276	200.0	1.027	0.161	0.096
2	26.276	200.0	1.031	0.136	0.117
3	26.276	200.0	1.025	0.130	0.124
4	26.276	200.0	1.313	0.113	-0.164
5	26.276	20.0	0.953	-0.088	-0.115
6	26.276	20.0	0.976	-0.077	-0.175
7	26.276	20.0	0.994	-0.089	-0.205
8	26.276	20.0	1.044	-0.102	-0.184

RUN 70					
1	25.724	190.0	1.017	0.137	0.103
2	25.724	190.0	1.027	0.107	0.128
3	25.724	190.0	1.030	0.101	0.129
4	25.724	190.0	1.333	0.098	-0.195
5	25.724	10.0	0.916	-0.057	-0.112
6	25.724	10.0	0.938	-0.040	-0.152
7	25.724	10.0	1.010	-0.066	-0.161
8	25.724	10.0	1.053	-0.103	-0.179

TABLE C-1 (CONTINUED)

RUN 71	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	25.727	180.0	1.033	0.060	0.114
2	25.727	180.0	1.042	0.046	0.133
3	25.727	180.0	1.033	0.036	0.144
4	25.727	180.0	1.397	0.024	-0.264
5	25.727	0.0	0.833	-0.016	-0.047
6	25.727	0.0	0.907	0.001	-0.084
7	25.727	0.0	0.969	-0.019	-0.133
8	25.727	0.0	0.994	-0.091	-0.194

RUN 72					
1	26.328	170.0	1.018	0.010	0.111
2	26.328	170.0	1.045	0.001	0.135
3	26.328	170.0	1.075	-0.001	0.142
4	26.328	170.0	1.392	-0.014	-0.234
5	26.328	350.0	0.818	-0.007	-0.063
6	26.328	350.0	0.925	0.025	-0.063
7	26.328	350.0	0.983	0.010	-0.127
8	26.328	350.0	0.945	-0.031	-0.169

TABLE C-1 (CONTINUED)

RUN 73	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	24.901	160.0	1.047	-0.023	0.107
2	24.901	160.0	1.064	-0.030	0.133
3	24.901	160.0	1.068	-0.031	0.136
4	24.901	160.0	1.414	-0.040	-0.239
5	24.901	340.0	0.818	0.000	-0.089
6	24.901	340.0	0.949	0.047	-0.144
7	24.901	340.0	1.065	0.045	-0.167
8	24.901	340.0	1.030	0.031	-0.191

RUN 75					
1	25.379	150.0	1.041	-0.090	0.085
2	25.379	150.0	1.052	-0.079	0.116
3	25.379	150.0	1.056	-0.080	0.118
4	25.379	150.0	1.309	-0.095	-0.148
5	25.379	330.0	0.905	0.062	-0.134
6	25.379	330.0	0.993	0.068	-0.191
7	25.379	330.0	1.061	0.065	-0.203
8	25.379	330.0	1.026	0.056	-0.197

TABLE C-1 (CONTINUED)

RUN 76	SPEED	ANGLE	LONGITUD. VELOCITY (V_x/V)	TANGENT VELOCITY (V_t/V)	RADIAL VELOCITY (V_r/V)
1	26.128	240.0	1.004	0.322	0.032
2	26.128	240.0	1.022	0.262	0.030
3	26.128	240.0	1.033	0.244	0.020
4	26.128	240.0	1.041	0.219	0.016
5	26.128	60.0	0.984	-0.256	-0.085
6	26.128	60.0	1.008	-0.236	-0.087
7	26.128	60.0	1.000	-0.208	-0.096
8	26.128	60.0	1.008	-0.201	-0.093

RUN 77

1	25.996	280.0	1.000	0.304	-0.037
2	25.996	280.0	1.023	0.250	-0.081
3	25.996	280.0	1.033	0.245	-0.101
4	25.996	280.0	1.009	0.208	-0.090
5	25.996	100.0	0.985	-0.242	0.001
6	25.996	100.0	1.000	-0.221	0.017
7	25.996	100.0	1.006	-0.201	0.003
8	25.996	100.0	0.999	-0.201	0.013

APPENDIX D

TABULATED DATA FROM BOUNDARY LAYER PROFILE MEASUREMENTS

Units are presented as the original data were recorded.

Speeds are given in feet per second.

Pressures are given in pounds per square foot.

TABLE D-1

BOUNDARY LAYER VELOCITY PROFILE DATA FROM RAKE #1

Tube No.	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞
1	200.33032	7.59973	0.71824	211.83374	11.09957	0.72280	287.26440	17.59383	0.70424	314.20752	19.37373	0.69250
2	202.34961	6.59920	0.62368	213.85303	10.68578	0.69585	289.28369	18.27438	0.73148	316.22681	20.00117	0.71493
3	206.33472	7.44521	0.70364	217.83813	11.68934	0.76120	293.26880	19.82274	0.79345	320.21191	22.00525	0.78657
4	210.32007	7.98365	0.75452	221.82349	12.19600	0.79420	297.25415	20.84895	0.83453	324.19727	22.84727	0.81666
5	216.64331	8.60355	0.81311	228.14673	13.24329	0.86240	303.57739	21.54794	0.86251	330.52051	25.38954	0.90754
6	222.91333	7.52537	0.71121	234.41675	12.92866	0.84191	309.84741	21.68530	0.86801	336.79053	26.11024	0.93330
7	231.25562	8.03847	0.75970	242.75903	13.19224	0.85907	318.18970	22.26762	0.89132	345.13281	26.72490	0.95527
8	239.54492	8.24650	0.77937	251.04834	13.55074	0.88242	326.47900	22.75456	0.91081	353.42212	27.37064	0.97835
9	250.01294	9.90284	0.93590	261.51636	14.62102	0.95211	336.94702	24.04698	0.96254	363.89014	28.51169	1.01914
10	260.48071	9.37908	0.88640	271.98413	14.39917	0.93767	347.41479	24.15779	0.96698	374.35791	28.81841	1.03010
11	270.78931	9.49373	0.89724	282.29272	14.62029	0.95207	357.72339	24.38618	0.97612	384.66650	29.22139	1.04450
12	279.76929	9.67989	0.91483	291.27271	14.82727	0.96554	366.70337	24.49945	0.98065	393.64648	29.28250	1.04669
13	291.83105	10.86771	1.02709	303.33447	15.25474	0.99338	378.76514	24.81647	0.99334	405.70825	29.18263	1.04312
	Run 109 at a speed of 10.581 ft/sec			Run 110 at a speed of 15.356 ft/sec			Run 111 at a speed of 24.983 ft/sec			Run 112 at a speed of 27.976 ft/sec		

These data are recorded as originally measured during the full-scale trial.

TABLE D-2

BOUNDAR LAYER VELOCITY PROFILE DATA FROM RAKE #2

Tube No.	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞
1	329.13501	3.70904	0.35054	339.93970	7.24911	0.47206	438.27637	12.29871	0.49229	470.28809	15.86352	0.56703
2	331.15430	4.98974	0.47157	341.95898	7.77609	0.50637	440.29565	13.51381	0.54092	472.30737	17.15553	0.61322
3	335.13940	4.02219	0.38013	345.94409	7.93153	0.51650	444.28076	14.95493	0.59861	476.29248	18.61815	0.66550
4	339.12476	7.53242	0.71188	349.92944	8.87716	0.57808	448.26611	13.79780	0.55229	480.27783	14.79176	0.52872
5	345.44800	4.77749	0.45151	356.25262	3.55262	0.23134	454.58936	6.01076	0.24060	486.60107	6.89035	0.24629
6	351.71802	5.35817	0.50639	362.52271	9.93707	0.64710	460.85936	17.97720	0.71958	492.87109	22.60088	0.80786
7	360.06030	6.76802	0.63964	370.86499	11.03899	0.71885	469.20166	19.82164	0.79341	501.21338	24.03192	0.85901
8	368.34961	6.40468	0.60530	379.15430	11.35718	0.73957	477.49097	20.39211	0.81624	509.50269	24.97139	0.89259
9	378.81763	8.47372	0.80084	389.62231	12.89676	0.83983	487.95898	21.76712	0.87128	519.97070	26.37132	0.94263
10	389.28540	8.74029	0.82603	400.09009	13.02183	0.84797	498.42676	22.42760	0.89772	530.43848	27.11757	0.96930
11	399.59399	6.85868	0.64820	410.39868	12.69788	0.82688	508.73535	22.52722	0.90171	540.74707	27.31898	0.97650
12	408.57397	7.74182	0.73167	419.37866	13.02380	0.84810	517.71533	22.73282	0.90994	549.72705	27.32373	0.97667
13	420.63574	10.81375	1.02199	431.44043	14.72382	0.95881	529.77710	23.15332	0.92677	561.78882	27.60495	0.98673
	Run 109 at a speed of 10.581 ft/sec			Run 110 at a speed of 15.356 ft/sec			Run 111 at a speed of 24.983 ft/sec			Run 112 at a speed of 27.976 ft/sec		

These data are recorded as originally measured during the full-scale trial.

TABLE D-3

BOUNDARY LAYER VELOCITY PROFILE DATA FROM RAKE #3

Tube	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞
1	181.41943	7.49548	0.70839	181.45850	11.28375	0.73479	213.05273	18.09671	0.72437	224.83691	21.42642	0.76588
2	183.43872	6.20021	0.58597	183.47778	10.58230	0.68911	215.07202	18.40314	0.73663	226.85620	22.07358	0.78901
3	187.42383	4.99946	0.47249	187.46289	10.18250	0.66308	219.05713	18.51292	0.74103	230.84131	17.78261	0.63563
4	191.40918	6.85754	0.64810	191.44824	11.69790	0.76176	223.04248	20.28497	0.81196	234.82666	24.48473	0.87519
5	197.73242	8.72044	0.82416	197.77148	12.63657	0.82289	229.36572	21.09735	0.84447	241.14990	25.68332	0.91804
6	204.00244	7.80038	0.73720	204.04150	12.00138	0.78152	235.63574	21.33710	0.85407	247.41992	26.29813	0.94001
7	212.34473	8.04850	0.76065	212.38379	12.37109	0.80560	243.97803	21.54605	0.86243	255.76221	26.89302	0.96128
8	220.63403	8.16554	0.77171	220.67310	12.35732	0.80470	252.26733	22.49277	0.90033	264.05151	27.43854	0.98078
9	231.10205	9.14642	0.86442	231.14111	14.24618	0.92770	262.73535	23.17479	0.92763	274.51953	27.89482	0.99709
10	241.56982	8.43393	0.79708	241.60889	13.70707	0.89260	273.20312	23.25084	0.93067	284.98730	27.98917	1.00046
11	251.87842	8.42791	079651	251.91748	13.68165	0.89094	283.51172	23.35841	0.93498	295.29590	28.14420	1.00600
12	260.85840	8.53001	0.80616	260.89746	14.14196	0.92092	292.49170	23.57079	0.94348	304.27588	28.44716	1.01683
13	272.92017	10.27984	0.97153	272.95923	14.91623	0.97134	304.55347	24.29681	0.97254	316.33765	28.83528	1.03070
	Run 109 at a speed of 10.581 ft/sec			Run 110 at a speed of 15.356 ft/sec			Run 111 at a speed of 24.983 ft/sec			Run 112 at a speed of 27.976 ft/sec		

These data are recorded as originally measured during the full-scale trial.

TABLE D-4

BOUNDARY LAYER VELOCITY PROFILE DATA FROM RAKE #4

Tube No.	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞
1	185.98633	7.91087	0.74765	191.52441	11.55608	0.75253	214.21045	16.23781	0.64996	235.57886	20.15054	0.72027
2	188.00562	7.07025	0.66820	193.54370	11.19429	0.72897	216.22974	16.66031	0.66687	237.59814	20.82239	0.74429
3	191.99072	7.70084	0.72780	197.52881	12.01248	0.78225	220.21484	17.94849	0.71843	241.58325	22.37097	0.79964
4	195.97607	8.03830	0.75969	201.51416	12.69193	0.82649	224.20020	19.07053	0.76335	245.56860	23.46034	0.83858
5	202.29932	10.02961	0.94789	207.83740	13.61079	0.88633	230.52344	21.70911	0.86896	251.89185	24.50223	0.87582
6	208.56934	9.30519	0.87942	214.10742	13.16505	0.85730	236.79346	21.79477	0.87239	258.16187	25.20325	0.90088
7	216.91162	9.60660	0.90791	222.44971	13.69865	0.89205	245.13574	22.57814	0.90375	266.50415	25.79132	0.92190
8	225.20093	9.52721	0.90040	230.73901	14.08595	0.91727	253.42505	23.12282	0.92555	274.79346	26.92575	0.96245
9	235.66895	10.57829	0.99974	241.20703	15.11401	0.98422	263.89307	22.85297	0.91475	285.26147	28.57956	1.02156
10	246.13672	9.89004	0.93469	251.67480	14.61969	0.95203	274.36084	22.95523	0.91884	295.72925	28.95377	1.03494
11	256.44531	9.87183	0.93297	261.98340	14.55417	0.94776	284.66943	23.95482	0.95885	306.03784	29.52177	1.05524
12	265.42529	9.94863	0.94023	270.96338	14.70057	0.95729	293.64941	24.36505	0.97527	315.01782	29.81131	1.06559
13	277.48706	10.35079	0.97824	283.02515	15.51241	1.01016	305.71118	25.55388	1.02286	327.07959	30.35669	1.08508
	Run 109 at a speed of 10.581 ft/sec			Run 110 at a speed of 15.356 ft/sec			Run 111 at a speed of 24.983 ft/sec			Run 112 at a speed of 27.976 ft/sec		

These data are recorded as originally measured during the full-scale trial.

TABLE D-5

BOUNDARY LAYER VELOCITY PROFILE DATA FROM RAKE #5

Tube No.	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞
1	189.71167	7.00500	0.66203	199.21753	10.25654	0.66790	235.15771	14.93994	0.59801	246.90796	18.35358	0.65604
2	191.73096	5.77093	0.54540	201.23682	9.50723	0.61911	237.17700	15.27993	0.61162	248.92725	19.43163	0.69457
3	195.71606	6.39814	0.60468	205.22192	10.26597	0.66851	241.16211	16.84044	0.67408	252.91235	20.96257	0.74930
4	199.70142	6.77242	0.64005	209.20728	10.78591	0.70237	245.14746	18.12195	0.72538	256.89771	22.08386	0.78938
5	206.02466	8.65222	0.81771	215.53052	12.17315	0.79271	251.47070	18.73529	0.74993	263.22095	23.41289	0.83688
6	212.29468	28.57285	2.70038	221.80054	27.57167	1.79545	257.74072	31.17010	1.24766	269.49097	29.53906	1.05586
7	220.63696	8.30978	0.78535	230.14282	11.89575	0.77464	266.08301	19.92735	0.79764	277.83325	24.82066	0.88720
8	228.92627	8.63905	0.81646	238.43213	12.20506	0.79479	274.37231	20.74188	0.83025	286.12256	25.56845	0.91393
9	239.39429	9.07196	0.85738	248.90015	13.32817	0.86792	284.84033	21.98070	0.87983	296.59058	26.68210	0.95374
10	249.86206	8.49556	0.80290	259.36792	13.15112	0.85639	295.30811	22.35057	0.89464	307.05835	27.29900	0.97579
11	260.17065	8.53918	0.80703	269.67651	13.52937	0.88103	305.61670	23.05371	0.92278	317.36694	28.04327	1.00239
12	269.15063	8.79716	0.83141	278.65649	13.93445	0.90740	314.59668	23.91608	0.95730	326.34692	28.46823	1.01758
13	281.21240	10.47859	0.99032	290.71826	14.74310	0.96006	326.65845	24.73071	0.98991	338.40869	29.51459	1.05499
	Run 109 at a speed of 10.581 ft/sec			**Run 110 at a speed of 15.356 ft/sec**			**Run 111 at a speed of 24.983 ft/sec**			**Run 112 at a speed of 27.976 ft/sec**		

These data are recorded as originally measured during the full-scale trial.

TABLE D-6

BOUNDARY LAYER VELOCITY PROFILE DATA FROM RAKE #7

Tube No.	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞
1	185.60596	6.93775	0.65568	202.18872	8.77973	0.57173	180.18311	16.69881	0.66841	507.12720	9.28361	0.33184
2	187.62524	5.19404	0.49088	204.20801	7.78600	0.50702	182.20239	17.51555	0.70110	509.14648	11.28136	0.40325
3	191.61035	6.28912	0.59438	208.19312	9.30283	0.60580	186.18750	18.60602	0.74475	513.13159	24.05957	0.86000
4	195.59570	6.54974	0.61901	212.17847	9.86060	0.64212	190.17285	19.58018	0.78375	517.11694	14.59347	0.52164
5	201.91895	8.32291	0.78659	218.50171	11.10528	0.72317	196.49609	19.77946	0.79172	523.44019	14.60101	0.52191
6	208.18896	6.49181	0.61353	224.77173	9.84893	0.64136	202.76611	19.78165	0.79181	529.71021	13.65758	0.48818
7	216.53125	7.03333	0.66471	233.11401	10.13063	0.65970	211.10840	19.78851	0.79208	538.05249	27.06564	0.96745
8	224.82056	7.62017	0.72017	241.40332	10.69417	0.69640	219.39771	20.87964	0.83576	546.34180	17.04990	0.60944
9	235.28857	24.45383	2.31110	251.87134	22.17517	1.44403	229.86572	21.42374	0.85754	556.80981	17.51057	0.62591
10	245.75635	8.69511	0.82176	262.33911	11.65198	0.75877	240.33350	21.35316	0.85471	567.27759	27.79460	0.99350
11	256.06494	8.81390	0.83299	272.64771	11.85376	0.77191	250.64209	21.36186	0.85506	577.58618	23.70879	0.84746
12	265.04492	9.05724	0.85599	281.62769	12.43824	0.80997	259.62207	21.56508	0.86320	586.56616	20.06119	0.71708
13	277.10669	9.18018	0.86761	293.68945	13.43088	0.87461	271.68384	23.42415	0.93761	598.62793	22.37408	0.79975
	Run 109 at a speed of 10.581 ft/sec			Run 110 at a speed of 15.356 ft/sec			Run 111 at a speed of 24.983 ft/sec			Run 112 at a speed of 27.976 ft/sec		

These data are recorded as originally measured during the full-scale trial.

TABLE D-7

BOUNDARY LAYER VELOCITY PROFILE DATA FROM RAKE #8

Tube No.	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞	Total Head (lb/ft^2)	Dynamic Head (ft/sec)	U/U_∞
1	200.72046	8.19557	0.77455	209.95264	11.55324	0.75234	274.33594	17.90654	0.71675	308.44067	20.71524	0.74046
2	202.73975	7.21642	0.68201	211.97192	11.03098	0.71833	276.35522	31.04192	1.24253	310.45996	32.46811	1.16056
3	206.72485	8.02851	0.75876	215.95703	12.16788	0.79237	280.34033	20.56000	0.82296	314.44507	23.54480	0.84160
4	210.71021	13.14696	1.24250	219.94238	12.78880	0.83280	284.32568	11.45837	0.45865	318.43042	17.14398	0.61280
5	217.03345	10.11964	0.95639	226.26562	13.95872	0.90898	290.64893	21.75708	0.87088	324.75366	25.83395	0.92342
6	223.30347	9.37824	0.88633	232.53564	13.44707	0.87567	296.91895	22.29915	0.89258	331.02368	26.58687	0.95033
7	231.64575	9.87455	0.93323	240.87793	13.80604	0.89904	305.26123	22.85460	0.91481	339.36597	27.47127	0.98195
8	239.93506	9.86938	0.93274	249.16724	14.06753	0.91607	313.55054	23.22873	0.92979	347.65527	28.12883	1.00545
9	250.40308	10.93446	1.03340	259.63525	22.50247	1.46535	324.01855	24.33563	0.97409	358.12329	29.19507	1.04356
10	260.87085	20.16031	1.90532	270.10303	20.42485	1.33006	334.48633	31.03336	1.24219	368.59106	31.47452	1.12504
11	271.17944	10.27207	0.97080	280.41162	14.61238	0.95155	344.79492	24.58411	0.98404	378.89966	29.23724	1.04507
12	280.15942	10.35735	0.97886	289.39160	14.70300	0.95745	353.77490	24.62715	0.98576	387.87964	29.26933	1.04622
13	292.22119	11.04833	1.04416	301.45337	15.33656	0.99871	365.83667	24.92946	0.99786	399.94141	29.42375	1.05174
	Run 109 at a speed of 10.581 ft/sec			Run 110 at a speed of 15.356 ft/sec			Run 111 at a speed of 24.983 ft/sec			Run 112 at a speed of 27.976 ft/sec		

These data are recorded as originally measured during the full-scale trial.

APPENDIX E

TABULATED DATA FROM TIME DEPENDENT PRESSURE MEASUREMENTS

Units are presented as the original data were recorded.

Pressures are given in pounds per square foot.

TABLE E-1 - TIME DEPENDENT PRESSURE DATA FROM EXPERIMENT 4 RUN 205

Propeller Blade Position	Pressure Gauge No.				
	T1	T2	R1	R2	C
Degrees					
0	9.1722	5.3780	13.3628	15.9946	26.7059
6	9.1775	5.3383	13.2571	34.3693	26.6341
12	9.1567	5.3275	13.3199	24.0017	26.5546
18	9.1728	5.3532	13.3090	29.3193	26.5926
24	9.1830	5.3692	13.3031	29.7556	26.5312
30	9.2021	5.3682	13.3600	29.2793	26.9171
36	9.1923	5.3280	13.2584	46.0951	26.8944
42	9.1565	5.3724	13.3517	15.3922	26.7182
48	9.1946	5.3554	13.3007	29.3192	26.7939
54	9.1749	5.3298	13.2910	33.1708	26.5920
60	9.1601	5.3558	13.3364	23.7223	26.7791
66	9.1969	5.3518	13.2831	30.9075	26.6693
72	9.1786	5.3783	13.3560	24.5851	26.7788
78	9.2151	5.3409	13.3001	38.3772	26.8107
84	9.1545	5.3333	13.2824	32.6672	26.5039
90	9.1715	5.3808	13.3558	17.9316	26.5697
96	9.1813	5.3205	13.2584	32.0809	26.3646
102	9.1515	5.3414	13.3263	27.2490	26.6706
108	9.1814	5.3432	13.3014	27.4903	26.6325
114	9.1793	5.3690	13.3090	27.0856	26.5172
120	9.1965	5.3619	13.3520	26.0168	26.4910

TABLE E-1 (CONTINUED)

Propeller Blade Position Degrees	Pressure Gauge No. T1	T2	R1	R2	C
126	9.1853	5.3207	13.2574	42.9699	26.5569
132	9.1493	5.3657	13.3324	22.9904	26.5253
138	9.1987	5.3511	13.3118	24.5876	26.4940
144	9.1662	5.3319	13.2766	33.4738	26.6142
150	9.1632	5.3383	13.3321	21.3603	26.7795
156	9.1903	5.3584	13.2836	31.3232	26.5202
162	9.1775	5.3750	13.3481	25.0706	26.5684
168	9.2193	5.3420	13.3113	40.0547	26.6954
174	9.1626	5.3394	13.2795	35.1383	26.4845
180	9.1741	5.3738	13.3573	17.6000	26.4525
186	9.1768	5.3368	13.2601	36.9573	26.4616
192	9.1571	5.3270	13.3201	24.0897	26.4669
198	9.1768	5.3527	13.3083	30.5194	26.5603
204	9.1856	5.3750	13.3127	27.6517	26.6252
210	9.2043	5.3645	13.3559	31.5855	26.6280
216	9.1878	5.3247	13.2587	46.1157	26.4943
222	9.1587	5.3706	13.3526	20.9536	26.5488
228	9.1943	5.3560	13.2960	30.5037	26.6563
234	9.1771	5.3318	13.2976	28.9742	26.5775
240	9.1626	5.3557	13.3353	28.8341	26.6792
246	9.1959	5.3521	13.2834	31.8332	26.5560

TABLE E-1 (CONTINUED)

Propeller Blade Position Degrees	Pressure Gauge No. T1	T2	R1	R2	C
252	9.1809	5.3732	13.3596	24.8461	26.7290
258	9.2127	5.3403	13.2940	41.6857	26.5887
264	9.1593	5.3321	13.2888	30.3936	26.5677
270	9.1701	5.3798	13.3535	18.0049	26.6654
276	9.1801	5.3183	13.2536	36.2060	26.6084
282	9.1558	5.3389	13.3335	25.6526	26.5011
288	9.1801	5.3468	13.2972	29.8841	26.6485
294	9.1846	5.3672	13.3144	25.6555	26.6613
300	9.1960	5.3648	13.3542	28.2432	26.7857
306	9.1921	5.3216	13.2559	43.8568	26.6590
312	9.1480	5.3640	13.3386	20.8507	26.6643
318	9.1948	5.3519	13.3039	30.3571	26.6948
324	9.1739	5.3277	13.2806	29.5287	26.7083
330	9.1605	5.3438	13.3354	21.9696	26.5719
336	9.1988	5.3600	13.2821	31.3234	26.7815
342	9.1758	5.3732	13.3539	19.0306	26.5731
348	9.2177	5.3398	13.3045	40.9340	26.5990
354	9.1615	5.3337	13.2770	33.4631	26.6135
360	9.1722	5.3780	13.3678	15.9946	26.7059

TABLE E-2 - TIME DEPENDENT PRESSURE DATA FROM EXPERIMENT 4 RUN 208

Propeller Blade Position Degrees	T1	T2	R1	R2	C
	Pressure Gauge No.				
0	14.4873	7.2781	16.3471	91.4337	25.3684
6	14.4872	7.2719	16.3437	91.7635	25.3643
12	14.4859	7.2707	16.3465	91.5709	25.3707
18	14.4881	7.2769	16.3507	91.5858	25.3733
24	14.4906	7.2780	16.3516	91.5632	25.3647
30	14.4831	7.2749	16.3502	91.6333	25.3717
36	14.4781	7.2783	16.3502	91.6164	25.3658
42	14.4846	7.2788	16.3510	91.7698	25.3664
48	14.4891	7.2776	16.3564	92.0984	25.3780
54	14.4804	7.2786	16.3566	91.7975	25.3663
60	14.4807	7.2794	16.3525	91.7010	25.3733
66	14.4825	7.2751	16.3526	91.9264	25.3543
72	14.4814	7.2753	16.3521	91.6777	25.3682
78	14.4858	7.2790	16.3529	91.9493	25.3493
84	14.4830	7.2813	16.3531	91.6407	25.3702
90	14.4770	7.2781	16.3491	91.6432	25.3720
96	14.4825	7.2801	16.3473	91.6069	25.3697
102	14.4845	7.2820	16.3468	91.7867	25.3618
108	14.4849	7.2852	16.3506	91.9504	25.3694
114	14.4846	7.2826	16.3490	91.4024	25.3610
120	14.4842	7.2780	16.3441	91.6001	25.3680

TABLE E-2 (CONTINUED)

Propeller Blade Position	Pressure Gauge No.				
	T1	T2	R1	R2	C
Degrees					
126	14.4832	7.2776	16.3464	92.0020	25.3447
132	1[illegible].4878	7.2771	16.3539	91.6409	25.3513
138	14.4918	7.2789	16.3568	91.8530	25.3574
144	14.4868	7.2792	16.3539	92.0728	25.3588
150	14.4856	7.2771	16.3552	91.9031	25.3785
156	14.4850	7.2737	16.3518	91.7536	25.3741
162	14.4869	7.2759	16.3510	91.5983	25.3766
168	14.4903	7.2825	16.3593	91.8170	25.3586
174	14.4865	7.2813	16.3574	91.7462	25.3576
180	14.4813	7.2785	16.3483	91.6169	25.3663
186	14.4798	7.2757	16.3455	91.9542	25.3750
192	14.4814	7.2750	16.3462	92.0302	25.3650
198	14.4886	7.2825	16.3483	91.4429	25.3762
204	14.4856	7.2844	16.3477	91.4737	25.3635
210	14.4792	7.2812	16.3466	91.8381	25.3643
216	14.4772	7.2804	16.3446	91.6851	25.3617
222	14.4827	7.2792	16.3446	91.8381	25.3356
228	14.4913	7.2820	16.3550	91.7774	25.3666
234	14.4873	7.2830	16.3559	92.0694	25.3691
240	14.4796	7.2827	16.3501	91.6217	25.3598
246	14.4823	7.2811	16.3531	91.7280	25.3650

TABLE E-2 (CONTINUED)

Propeller Blade Position Degrees	Pressure Gauge No. T1	T2	R1	R2	C
252	14.4861	7.2797	16.3558	91.6658	25.3603
258	14,4874	7.2826	16.3540	91.5194	25.3706
264	14.4824	7.2839	16.3501	91.5100	25.3490
270	14.4791	7.2831	16.3485	91.6140	25.3773
276	14.4794	7.2835	16.3479	91.6466	25.3687
282	14.4774	7.2833	16.3451	91.4363	25.3640
288	14.4838	7.2833	16.3490	91.6349	25.3620
294	14.4862	7.2837	16.3526	91.8756	25.3682
300	14.4774	7.2826	16.3473	91.7273	25.3731
306	14.4767	7.2785	16.3449	91.6982	25.3564
312	14.4859	7.2747	16.3519	91.5410	25.3561
318	14.4877	7.2780	16.3544	91.6193	25.3562
324	14.4807	7.2789	16.3499	91.7879	25.3586
330	14.4786	7.2748	16.3488	91.5907	25.3561
336	14.4780	7.2743	16.3487	91.7882	25.3458
342	14.4809	7.2797	16.3491	91.6157	25.3569
348	14.4836	7.2801	16.3513	91.7359	25.3577
354	14.4831	7.2799	16.3518	91.6567	25.3554
360	14.4873	7.2781	16.3471	91.4337	25.3684

TABLE E-3 - TIME DEPENDENT PRESSURE DATA FROM EXPERIMENT 4 RUN 209

Propeller Blade Position	Pressure Gauge No.				
	T1	T2	R1	R2	C
Degrees					
0	13.9278	5.2338	14.2483	96.8719	24.1033
6	13.9413	5.2087	14.2250	96.8983	24.1010
12	13.9371	5.2540	14.2515	97.4734	24.0976
18	13.9669	5.2803	14.2661	97.1797	24.0979
24	14.0019	5.2758	14.2789	96.9944	24.0969
30	13.9703	5.2502	14.2603	97.8536	24.1030
36	13.9190	5.2517	14.2372	96.9388	24.0992
42	13.9223	5.2547	14.2590	96.1146	24.1011
48	13.9533	5.2149	14.2433	96.6590	24.1020
54	13.9357	5.2524	14.2525	97.2781	24.0987
60	13.9581	5.2886	14.2809	96.1525	24.0988
66	13.9822	5.2900	14.2775	96.6484	24.0985
72	13.9981	5.2620	14.2787	96.6926	24.1004
78	13.9348	5.2432	14.2391	97.0956	24.1054
84	13.8960	5.2549	14.2384	96.1778	24.1010
90	13.9376	5.2379	14.2516	97.1767	24.1006
96	13.9262	5.2285	14.2287	97.1525	24.1006
102	13.9464	5.2664	14.2609	96.3052	24.0955
108	13.9548	5.3016	14.2745	96.1228	24.0955
112	13.9930	5.2826	14.2811	96.7832	24.0968
[illegible]	13.9697	5.2599	14.2667	96.6597	24.1008

TABLE E-3 (CONTINUED)

Propeller Blade Position	Pressure Gauge No.				
	T1	T2	R1	R2	C
Degrees					
126	13.9067	5.2551	14.2277	95.9253	24.1019
132	13.9293	5.2483	14.2452	96.4179	24.0994
138	13.9455	5.2232	14.2298	97.5471	24.1026
144	13.9515	5.2409	14.2344	96.4984	24.0983
150	13.9468	5.2826	14.2652	96.5116	24.0961
156	13.9803	5.2795	14.2650	97.2760	24.0948
162	14.0029	5.2650	14.2833	96.4718	24.0973
168	13.9386	5.2470	14.2432	96.3880	24.1006
174	13.9145	5.2440	14.2409	96.3322	24.1007
180	13.9405	5.2304	14.2522	96.8428	24.1004
186	13.9471	5.2044	14.2223	97.8328	24.1026
192	13.9409	5.2462	14.2483	96.9530	24.0998
198	13.9655	5.2821	14.2655	96.4369	24.0964
204	14.0003	5.2664	14.2715	96.3408	24.0966
210	13.9810	5.2468	14.2574	96.9100	24.1011
216	13.9116	5.2514	14.2338	96.5183	24.0998
222	13.9222	5.2578	14.2539	96.2986	24.0989
228	13.9494	5.2183	14.2356	96.9747	24.1008
234	13.9321	5.2443	14.2344	97.7389	24.0973
240	13.9580	5.2875	14.2718	95.9384	24.0952
246	13.9866	5.2878	14.2696	96.7940	24.0942

TABLE E-3 (CONTINUED)

Propeller Blade Position Degrees	Pressure Gauge No. T1	T2	R1	R2	C
252	14.0019	5.2712	14.2849	96.8193	24.0973
258	13.9363	5.2480	14.2504	97.0217	24.1014
264	13.9057	5.2601	14.2467	96.3751	24.0989
270	13.9435	5.2360	14.2610	96.7512	24.1045
276	13.9236	5.2335	14.2323	97.2190	24.0988
282	13.9412	5.2741	14.2596	95.9959	24.0956
288	13.9530	5.3010	14.2702	95.8432	24.0961
294	13.9900	5.2904	14.2773	96.0771	24.0952
300	13.9675	5.2636	14.2625	96.4150	24.1007
306	13.8934	5.2603	14.2265	95.7880	24.1035
312	13.9196	5.2520	14.2514	95.9129	24.1011
318	13.9217	5.2322	14.2312	96.8734	24.1052
324	13.9304	5.2452	14.2353	96.6074	24.0999
330	13.9423	5.2860	14.2632	96.1050	24.0976
336	13.9666	5.2935	14.2651	96.1014	24.0965
342	14.0010	5.2699	14.2809	96.7393	24.0979
348	13.9345	5.2520	14.2412	96.2979	24.1014
354	13.9141	5.2399	14.2321	96.3981	24.0992
360	13.9278	5.2338	14.2483	96.8719	24.1033